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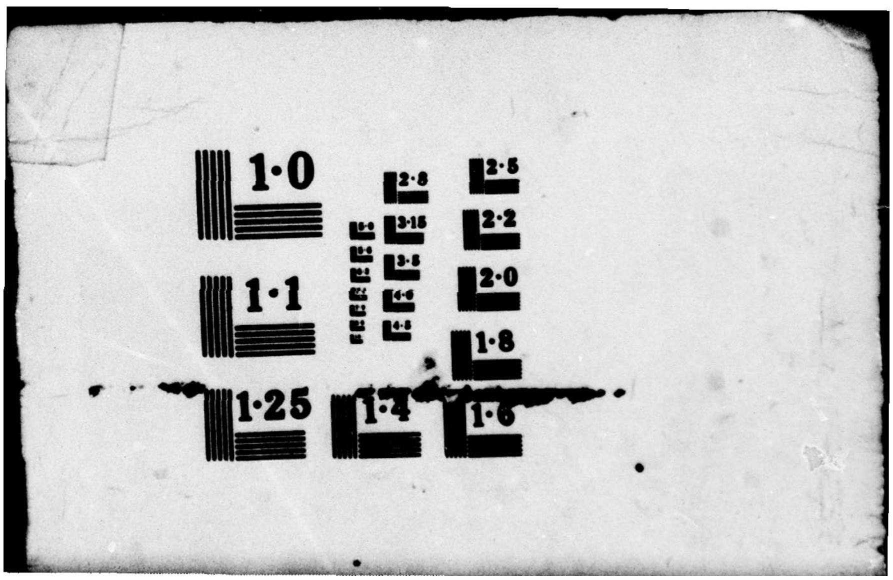
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Guidelines are presented for designing, operating, and managing dredged material containment areas to meet required effluent solids standards and to provide adequate storage volume. The guidelines are equally applicable to design of new containment areas and to evaluation of existing sites. Field investigations necessary to provide data for containment area design are described to include channel sediment investigations and foundation CONT'

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investigations at the containment area. Sample type and location, sampling equipment, and sample preservation techniques are included.

Laboratory testing procedures required to obtain data for sediment characterization, containment area design, and estimates of long-term storage capacity are given. Sediment characterization tests include salinity determination of near-bottom water and natural water content, Atterberg limits, organic content, specific gravity, and grain size analysis of the sediments. Sedimentation tests performed in an 8-in.-diam column are used to define settling behavior within the dredged material containment area. Procedures for both flocculent settling tests, generally applicable to freshwater sediments, and zone settling tests, generally applicable to saltwater sediments, are described. Results of conventional consolidation tests are used to estimate settlements due to self-weight consolidation of newly placed dredged material and consolidation of compressible foundation soils.

Procedures are given for containment area design for retention of suspended solids based on solids removal through gravity sedimentation. Separate design procedures for freshwater and saltwater sediments provide for determination of the respective surface area or detention time required to accommodate continuous dredged material disposal. Procedures are also given for estimation of the storage volume required for a single disposal activity and the corresponding ponding depths, freeboard requirements, and dike heights. Factors influencing containment area hydraulic efficiency are evaluated to include effects of short-circuiting, ponding depth, spur dikes, weir placement, and containment area shape.

Guidelines for estimation of gains in long-term storage capacity due to settlements within the containment area are presented. The guidelines are based on conventional consolidation theory modified to consider self-weight consolidation behavior of newly placed dredged material. The effects of foundation consolidation, time-rate of consolidation, and placement of sequential lifts of dredged material are also described.

Design and operational procedures for weirs are presented based on providing the capability of selective withdrawal of the clarified upper layer of ponded water. Weir design guidelines allow evaluation of the trade-off involved between the two most important weir design parameters, ponding depth and effective weir length. Operational procedures for weirs are outlined to include weir boarding, maintenance of adequate ponding depth, use of static head and depth of flow over the weir as operating parameters, and weir operation for undersized basins and for decanting surface water.

Containment area management activities are described which may be considered as possibilities for improving efficiency and prolonging the service life of containment areas. Separate activities may be performed before, during, and following the dredging operation and include site preparation, removal of existing dredged material for construction programs, surface water management, suspended solids monitoring, inlet and weir management, thin-lift placement, separation of coarse material, dredged material dewatering, and disposal area reuse management.

Summaries of research pertinent to designing, operating, and managing dredged material containment areas and example calculations are included in appendices to the main text.

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SUMMARY

The purpose of this report is to provide guidelines for designing, operating, and managing dredged material containment areas to provide adequate storage volume and to meet required effluent suspended solids standards.

Field investigations are required to determine properties of the sediments to be dredged. Grab samples taken at the sediment surface are sufficient for most maintenance projects. Foundation conditions at the containment area must also be determined using conventional soil sampling techniques if estimates of settlement are required.

Laboratory tests necessary to characterize channel sediments include salinity of near-bottom water, natural water content, Atterberg limits, organic content, specific gravity, and grain size analysis. Sedimentation tests performed in an 8-in.-diam column are satisfactory for defining dredged material settling behavior within the containment area. Settling behavior in a freshwater environment is best described by a flocculent settling test, while behavior in a saltwater environment is best described by a zone settling test. The same settling column can be used for both tests with minor procedural changes. Conventional consolidation tests are adequate for determining consolidation properties of dredged material and foundation soils.

Containment area design for meeting effluent suspended solids criteria is based on determination of a surface area or detention time required to accommodate a continuous dredged material disposal operation. The designs call for suspended solids removal by the process of gravity sedimentation allowing discharge of carrier water from the containment area. Suspended solids removal efficiency for freshwater sediments depends on the ponding depth as well as the properties of the particles. The saltwater design procedure provides suspended solids removal to levels of 1 to 2 g/ℓ.

Required storage capacity to accommodate dredged material is estimated based on correlation of in situ sediment void ratios with containment area void ratios at completion of dredging; these are determined

from the sedimentation tests. Gains in storage capacity through settlement of dredged material and foundation soils can be estimated using conventional settlement analysis based on consolidation test data. Use of available computer models is recommended for cases involving repetitive disposal operations and/or intermittent dewatering or removal of material.

Ponding depths should be as great as possible to provide longer detention times and reduce the effects of short-circuiting. A minimum ponding depth of 2 ft is recommended for sedimentation of solids during a continuous disposal activity. Short-circuiting and dead zones can be reduced by judicious placement of weirs or use of multiple weirs. The hydraulic efficiency of containment areas is greatly influenced by length-to-width ratio, with greater length-to-width ratios being better. Spur dikes may be used to increase the length-to-width ratio. Spur dikes should be approximately three fourths the length of the parallel side. One or two spur dikes are usually sufficient and three or four should be the maximum number used.

Ponding depth and effective weir length, the minimum width over which flow must pass, are the two most important parameters in weir design. Properly designed weirs allow selective withdrawal of the clarified upper layer of ponded water. Adequate ponding depth during the dredging operation can be maintained by controlling the weir crest elevation. The weir should be boarded to provide the greatest possible ponding depth to ensure the maximum possible efficiency. Static head or depth of flow over the weir may be used as an operating parameter to control an intermittent disposal operation if effluent suspended solids concentrations are unacceptable.

Various containment area management strategies may be used to prolong containment area service life and increase efficiency. Use of existing dredged material should be considered for dike raising or other construction to provide additional storage capacity. During the disposal operation, surface water should be managed to provide maximum ponding and then removed quickly following the disposal operation to initiate drying.

Suspended solids should be periodically monitored during the disposal operation to ensure that effluents remain within acceptable limits. Dredged material should be placed in as thin a lift as possible to enhance natural drying and potential gains in capacity through active dewatering and containment area reuse management activities.

PREFACE

This report synthesizes results of the Dredged Material Research Program (DMRP) pertinent to designing, operating, and managing dredged material containment areas. The DMRP was sponsored by the Office, Chief of Engineers, U. S. Army, and was assigned to the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES).

This study was conducted under Task 2C, Containment Area Operations (Mr. Newton C. Baker, Manager), of the Disposal Operations Project (Mr. Charles C. Calhoun, Jr., Manager). The study was conducted by the Water Resources Engineering Group (WREG) of the Environmental Engineering Division (EED), EL, under the general supervision of Dr. John Harrison, Chief, EL; Dr. Roger T. Saucier, Special Assistant, EL; and Mr. A. J. Green, Chief, EED. This report was written by Mr. Michael R. Palermo, WREG; Dr. Raymond L. Montgomery, Chief, WREG; and Ms. Marian E. Poindexter, WREG.

This report is also being published as Engineer Manual 1110-2-5006.

Director of WES during the study was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres (U. S. survey)	4046.856	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	3.785412	litres
gallons (U. S. liquid) per minute	3.785412	litres per minute
inches	2.54	centimetres
miles (U. S. statute)	1.609344	kilometres
ounces (U. S. fluid)	29.57353	cubic centimetres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per hour-square foot	0.04214011	kilograms per hour-square metre
square feet	0.09290304	square metres
square inches	6.4516	square centimetres
tons (2000 lb force) per square foot	95.76052	kilopascals

GUIDELINES FOR DESIGNING, OPERATING, AND MANAGING DREDGED MATERIAL CONTAINMENT AREAS

PART I: INTRODUCTION

Background

1. The purpose of this report is to provide guidelines for designing, operating, and managing dredged material containment areas to provide maximum storage volume and to meet required effluent solids standards. The guidelines presented are applicable to design of new containment areas and evaluation of existing sites and include data collection and sampling requirements, description of testing procedures, and design, operational, and management procedures.

2. Design procedures include the consideration of dredged material sedimentation and consolidation behavior and potential consolidation of foundation soils. Guidelines for containment area design for sedimentation were developed primarily for fine-grained material generated in maintenance dredging operations. Factors which improve containment area efficiency are presented and include weir design and location, effects of containment area size and shape, and use of interior spur dikes. Operational guidelines for containment areas during the dredging operation include weir operation and maintenance of adequate ponding depth. Guidelines for containment area management before, during, and after dredging operations to maximize efficiency and storage capacity are also presented.

3. This report does not contain information concerning treatment of contaminated effluents, design of containment area dikes, procedures for dredged material dewatering and densification, or disposal area reuse management practices. Information concerning these subjects is available in other U. S. Army Engineer Waterways Experiment Station (WES) Dredged Material Research Program (DMRP) reports.[1-4] Also, although not specifically covered in this report, guidelines have been developed by the DMRP for odor control, for mosquito and other insect

control, and for minimizing the adverse visual impact of disposal areas.[5-7] These factors should be considered in the earliest planning and design stages and carried through during construction and management phases.

Concepts of Containment Area Operation

4. Diked containment areas are used to retain dredged material solids while allowing the carrier water to be released from the containment area. The two objectives inherent in the design and operation of a containment area are: (a) to provide adequate storage capacity to meet dredging requirements and (b) to attain the highest possible efficiency in retaining solids during the dredging operation in order to meet effluent suspended solids requirements. These considerations are basically interrelated and depend upon effective design, operation, and management of the containment area.

5. The major components of a dredged material containment area are shown schematically in Figure 1. A tract of land is surrounded by dikes to form a confined surface area, and the dredged channel sediments are then pumped into this area hydraulically. The influent dredged material slurry can be characterized by suspended solids concentration,* particle gradation, type of carrier water (fresh or saline), and rate of inflow.

6. In some dredging operations, especially in the case of new work dredging, sand, clay balls, and/or gravel may be present. This coarse material (more than half >No. 40 sieve) rapidly falls out of suspension near the dredge inlet pipe forming a mound. The fine-grained material (more than half <No. 40 sieve) continues to flow through the containment area with most of the solids settling out of suspension, thereby occupying a given storage volume. The fine-grained dredged material is usually rather homogeneous and is easily characterized.

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* Procedures for determining and reporting suspended solids concentrations are presented in Appendix A.

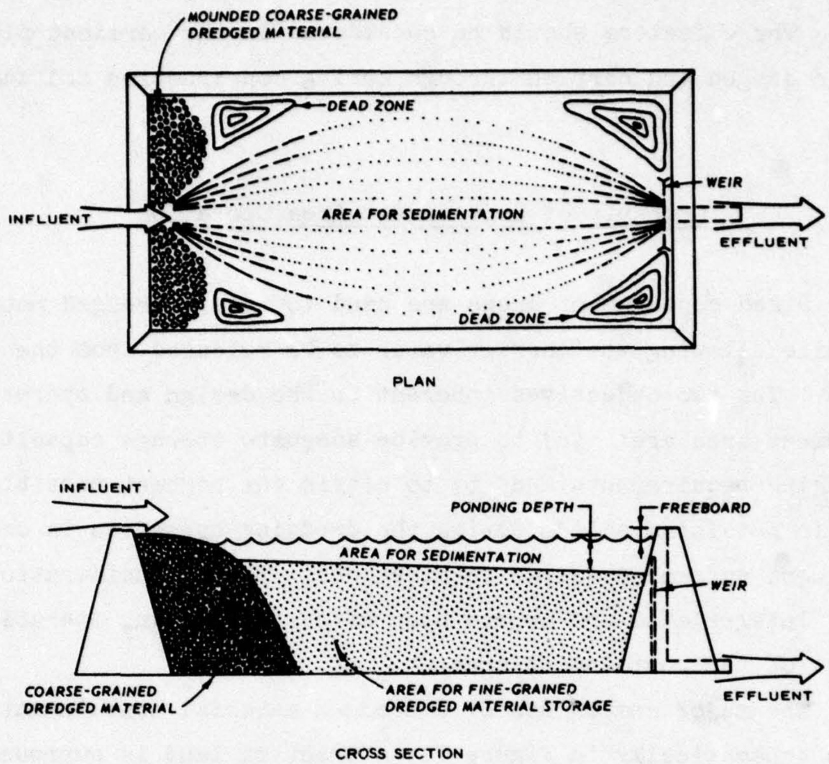


Figure 1. Conceptual diagram of a dredged material containment area (from Montgomery[8])

7. The clarified water is discharged from the containment area over a weir. This effluent may be characterized by its suspended solids concentration and rate of outflow. Effluent flow rate is approximately equal to influent flow rate for continuously operating disposal areas. Flow over the weir is controlled by the static head and the effective weir length provided. To promote effective sedimentation, ponded water is maintained in the area; the depth of water is controlled by the elevation of the weir crest. The thickness of the dredged material layer increases with time until the dredging operation is completed. Minimum freeboard requirements and mounding of coarse-grained material result in a ponded surface area smaller than the total surface area enclosed by the dikes. Dead spots in corners and other hydraulically inactive zones reduce the effective surface area, where sedimentation takes place, to considerably less than the ponded surface area.[9]

PART II: FIELD INVESTIGATIONS

8. Field investigations are necessary to provide data for containment area design. The channel must be surveyed to determine the volume of material to be dredged, and channel sediments must be sampled to obtain material for laboratory tests. The foundation soils within the proposed containment area must be sampled to obtain soil for laboratory testing so that potential settlement, an important parameter in long-term storage capacity estimates, can be determined. This Part of the report describes field investigations required to obtain the necessary samples for laboratory testing. Summaries of sampling, testing, and data requirements are given in Appendix B. The methods in common use for determining volumes of channel sediment to be dredged are well known and do not warrant discussion here.

Channel Sediment Investigations

Sample type and location

9. Samples of the channel sediments to be dredged are required for adequate characterization of the material and for use in sedimentation and consolidation testing. The level of effort required for channel sediment sampling is highly project-dependent. In the case of routine maintenance work, data from prior samplings and experience with similar material may be available, and the scope of field investigations may be reduced. For unusual maintenance projects or new work projects, more extensive field investigations will be required.

10. For maintenance work, channel investigations may be based on grab samples of sediment. Since bottom sediments are in an essentially unconsolidated state, grab samples are satisfactory for sediment characterization purposes and are easy and inexpensive to obtain. Grab sampling may indicate relatively homogeneous sediment composition, segregated pockets of coarse- and fine-grained sediment, and/or mixtures. If segregated pockets are present, samples should be taken at a sufficient number of locations in the channel to adequately define spatial variations in the sediment character. In any case, results of grab

sampling must allow estimation of the relative proportions of coarse- and fine-grained sediments present. Caution should be exercised in interpreting conditions indicated by grab samples since sediment surface samples do not indicate variation in sediment character with depth. For more detailed information, additional samples may be taken using conventional boring techniques.

11. Water samples should be taken at several locations near the sediment-water interface in the area to be dredged. Subsequent salinity tests on these samples indicate whether the dredging will be done in a freshwater or saltwater environment. Potential changes in salinity due to tides or seasonal flooding should also be considered.

12. Samples of sediments taken by conventional boring techniques are normally required only in the case of new work dredging. Based on information gained from initial grab sampling, locations for borings should be selected. Samples should be taken from within the major zones of spatial variation in sediment type or along the proposed channel center line at constant spacing to define stratification within the material to be dredged and to obtain representative samples. Borings should be advanced to the full depth of anticipated dredging if possible. This is normally done on a routine basis for new work projects to indicate type of material to be dredged and the degree of dredging difficulty since this information is required for the dredging contractor to use as a basis for bidding on the project.

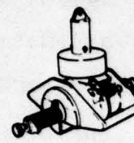
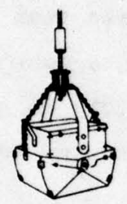
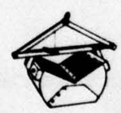
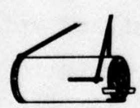
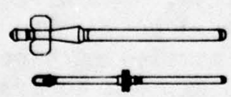
13. Sediment sampling equipment and procedures are described in another DMRP report.[10] Pertinent information regarding sediment samplers is also summarized in Table 1. Grab samplers as described in Table 1 will allow retrieval of sufficient amounts of sediment needed to perform characterization tests and sedimentation and consolidation tests, if required.

Sample quantity

14. The quantity of sediment samples to be collected should be determined by the designer based on the requirements for the laboratory tests to be performed. A quantity of sediment sufficient to perform the necessary characterization tests and to provide some material for

Table 1

Summary of Sediment Sampling Equipment

Sampler		Weight	Remarks
Peterson		39-93 lb	Samples 144-in.^{2} area to a depth of up to 12 in., depending on sediment texture
Shipek		150 lb	Samples 64-in.^{2} area to a depth of approximately 4 in.
Ekman		9 lb	Suitable only for very soft sediments
Ponar		45-60 lb	Samples 81-in.^{2} area to a depth of less than 12 in. Ineffective in hard clay
Drag bucket		Varies	Skims an irregular slice sediment surface. Available in assorted sizes and shapes
Phlegar tube		Variable 17-77 lb; fixed in excess of 90 lb	Shallow core samples may be obtained by self-weight penetration and/or pushing from boat. Depth of penetration dependent on weight and sediment texture
Conventional soil samplers			Conventional soil samplers may be employed using barge- or boat-mounted drilling equipment. Core samples attainable to full depth of dredging

the column settling tests should be collected from each established sampling point. It is recommended that at least 5 gal* of sediment be collected at each sampling station. Five-gallon containers are generally recommended for collecting the grab samples. Since most sampling will be performed from small motorboats, containers of this size are about the largest that can be handled efficiently.

15. A smaller sample of sediment should be collected from each fine-grained grab sample and placed in a small (about 8-oz) watertight jar for water content and specific gravity tests. Care should be taken to collect small sediment samples that appear to be most representative of the sediment sample as a whole.

16. After the characterization tests have been performed on grab samples from each sampling point, samples can be combined to meet requirements for the settling tests. Approximately 15 gal of channel sediment is required to perform the column settling tests described in Part III and outlined in detail in Appendix A.

Sample preservation

17. The laboratory tests outlined in this report do not require sophisticated sample preservation measures. There are two requirements:

a. Collect the samples in airtight and watertight containers.

b. Place the samples in a cold room (6 to 8°C) within 24 hours after sampling until the organic content of the samples can be determined. If the organic content is above 10 percent, the samples should remain in the cold room until testing is complete; otherwise, the samples need not be stored in the cold room. The in situ water content of the small samples must be maintained. These samples should not be allowed to drain nor should additional water be added when they are placed into the containers.

18. All sample containers should be clearly identified with labels, and the sample crew should keep a field log of the sampling activity. Laboratory testing should be accomplished on the samples as soon as practicable after sampling.

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 11. Metric (SI) units are used in this report when consistent with standard usage.

Containment Area Investigations

19. Field investigations must be performed at the containment area to define foundation conditions and to obtain samples for laboratory testing if estimates of long-term storage capacity are required. The extent of required field investigations is dependent upon project size and upon foundation conditions at the site. It is particularly important to define foundation conditions including depth, thickness, extent, and composition of foundation strata and to obtain undisturbed samples of compressible foundation soils and any previously placed dredged material. For new containment areas, the field investigations required for estimating long-term storage capacity should be planned and accomplished along with those required for the engineering design of the retaining dikes.

20. For existing containment areas, the foundation conditions may have been defined by previous subsurface investigations made in connection with dike construction. However, previous investigations may not have included sampling of compressible soils for consolidation tests; in most cases, suitable samples of any previously placed dredged material are not available. Field investigations must therefore be tailored to provide those items of information not already available.

21. Undisturbed samples of the compressible foundation soils can be obtained using conventional soil sampling techniques and equipment. If dredged material has previously been placed within the containment area, undisturbed samples must be obtained from borings taken within the containment area but not through existing dikes. The major problem in sampling existing containment areas is that the surface crust will not normally support conventional drilling equipment, and personnel sampling in these areas must use caution. Below the surface crust, fine-grained dredged material is usually soft, and equipment will sink rapidly if it breaks through the firmer surface. Lightweight drilling equipment, supported by mats, will normally be required if crust thickness is not well developed. In some cases, sampling may be accomplished manually, if sufficient dried surface crust has formed to support crew and equipment. More detailed information regarding equipment use in

containment areas may be found in another DMRP report.[11]

22. Water table conditions within the containment area must be determined in order to estimate loadings caused by placement of dredged material. This information must be obtained by means of piezometers which may also be used for measurement of groundwater conditions during the service life of the area. Other desired instrumentation such as settlement plates may also be installed within the containment area for monitoring various parameters.

23. Additional information regarding conventional sampling techniques and equipment and developing field exploration programs is given in Engineer Manual EM 1110-2-1907[12] and in another DMRP report.[2] Procedures for installation of piezometers and other related instrumentation are given in EM 1110-2-1908.[13]

PART III: LABORATORY TESTING

24. Laboratory tests are required primarily to provide data for sediment characterization, containment area design, and long-term storage capacity estimates. The laboratory tests and procedures described in this Part are essentially standard tests and generally follow procedures found in Standard Methods[14] and EM 1110-2-1906.[15] Other nonstandard tests not covered in the above references are outlined in detail in Appendix A. A flow chart illustrating the complete laboratory testing program for sediment samples is shown in Figure 2. Sediment character and requirements for sedimentation data and for long-term storage capacity estimates will dictate which laboratory tests are required. Not all laboratory tests indicated in Figure 2 are required for every application. The testing program for foundation materials includes only standard soil classification and consolidation testing and therefore is not illustrated by a flow chart. A summary of design data requirements is given in Appendix B.

25. The required magnitude of the laboratory testing program is highly project-dependent. Fewer tests are usually required when dealing with a relatively homogeneous material and/or when data are available from previous tests and experience, as is frequently the case in maintenance work. For unusual maintenance projects where considerable variation in sediment properties is apparent from samples or for new work projects, more extensive laboratory testing programs are required. Laboratory tests should always be performed on representative samples selected using sound engineering judgment.

Sediment Characterization Tests

26. A number of sediment characterization tests are required before settling tests can be performed. Visual classification will establish whether the sediment sample is predominantly fine-grained (more than half <No. 40 sieve) or coarse-grained (more than half >No. 40 sieve). Tests required on fine-grained sediments include natural water content, Atterberg limits, organic content, and specific gravity. The

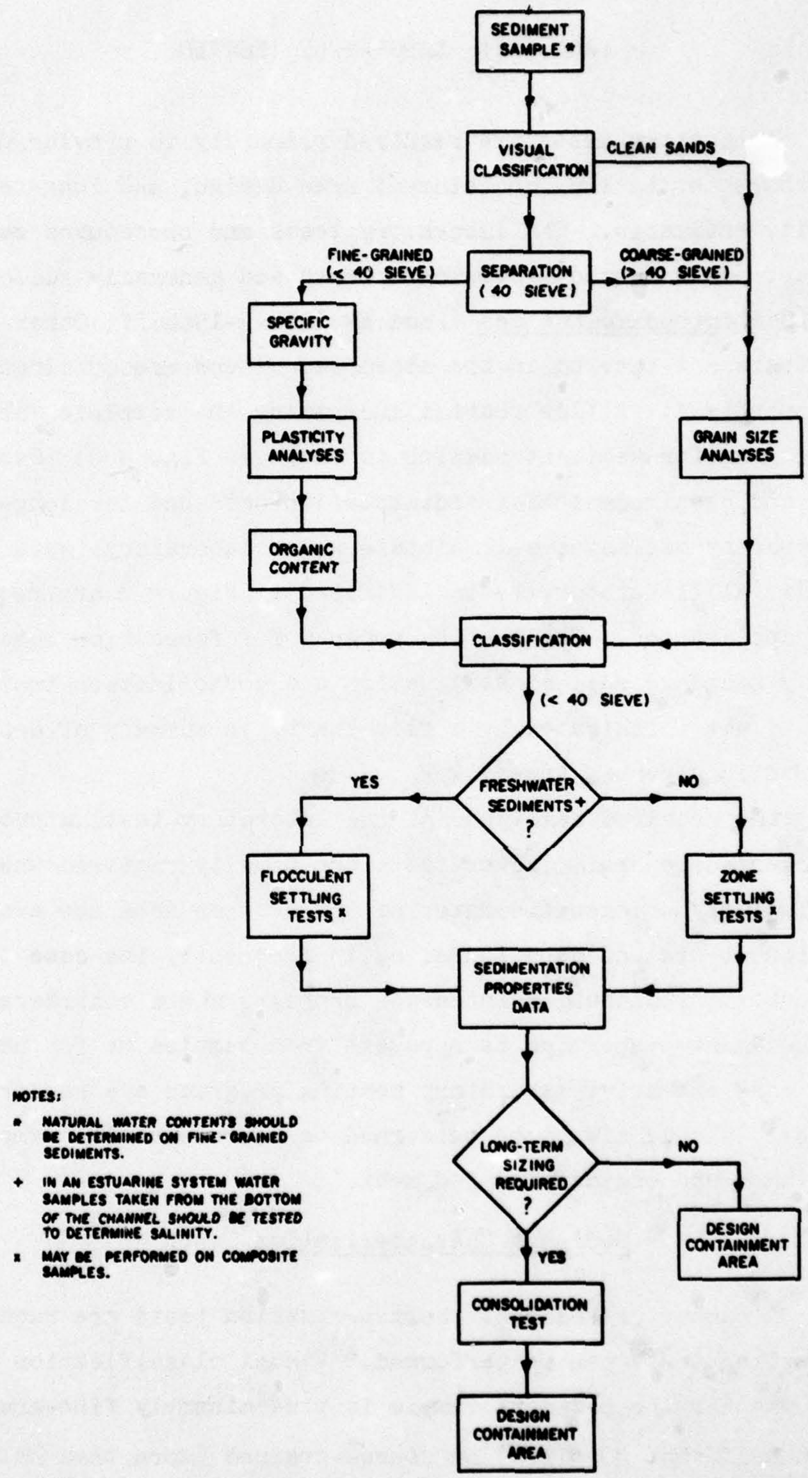


Figure 2. Flow chart depicting laboratory testing program for sediment samples (from Montgomery[8])

coarse-grained sediments require only grain size analyses. Results of these tests can be used to classify the sediments according to the Unified Soil Classification System (USCS).[16]

Salinity

27. Near-bottom water samples from the area to be dredged should be tested for salinity to determine whether the sediment source should be classified as freshwater or saltwater. This classification will determine the type settling tests required and influence the other characterization tests. If the water classifies as saline (>3 ppt), ambient water gathered during the field investigation or reconstituted salt water should be used when additional water is required in all subsequent characterization tests and in the sedimentation tests.

Water content

28. Water content is an important factor used in sizing dredged material containment areas. Water content determinations should be made on representative samples from borings or grab samples of fine-grained sediment obtained in the field investigation phase. In the case of mixtures of coarse- and fine-grained samples, the water content of the sample should be determined prior to separation on the No. 40 sieve as described below. The detailed test procedure for determining the water content is found in Appendix I of EM 1110-2-1906.[15] The water content is expressed on a dry weight basis as follows:

$$w = \frac{W_W}{W_S} \times 100\% \qquad (1)$$

where

w = water content, percent*

W_W = weight of water in sample, g

W_S = weight of solids in sample, g

Sample separation

29. It is emphasized that sediment character as determined from

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix E).

in situ samples is not indicative of dredged material behavior after dredging since the fine-grained (<No. 40 sieve) fraction will undergo natural segregation within the containment area and will behave independently of the coarse-grained (>No. 40 sieve) fraction. Therefore, the relative percentage (dry weight basis) of coarse- and fine-grained material should be determined by separation of a small portion of the sample using a No. 40 sieve and following procedures generally described in EM 1110-2-1906.[15]

30. If the coarse-grained fraction is less than 10 percent by dry weight, the sediment sample is considered to be fine grained and is treated as though all the material passed the No. 40 sieve; separation for further characterization tests is <u>not</u> required. If the coarse-grained fraction is greater than 10 percent by dry weight, the entire sample should be separated on the No. 40 sieve prior to further testing.

Grain size analyses

31. Grain size analyses as described below should be performed on coarse-grained samples or on the coarse-grained fraction of samples that are mixtures of coarse- and fine-grained material. These analyses are used to classify the coarse-grained portion of the sediments. The fine-grained material (passing the No. 40 sieve) should be used in the other characterization tests, sedimentation tests, and consolidation tests if required. Grain size analyses should follow the procedures contained in EM 1110-2-1906.[15] Hydrometer analyses can be used to define the grain size distribution of the fine-grained fraction if desired.

Plasticity analyses

32. In order to evaluate the plasticity of fine-grained samples of sediment, the Atterberg liquid limit (LL) and plastic limit (PL) must be determined. The LL is that water content above which the material is said to be in a semiliquid state and below which the material is in a plastic state. Similarly, the water content which defines the lower limit of the plastic state and the upper limit of the semisolid state is termed the PL. The plasticity index (PI), defined as the numerical difference between the LL and the PL, is used to express the plasticity of the sediment. Plasticity analyses should be performed on the

separated fine-grained fraction (<No. 40 sieve) of sediment samples. A detailed explanantion of the LL and PL test procedures and apparatus can be found in Appendix III of EM 1110-2-1906.[15]

Organic content

33. For classification purposes, the organic content generally need not be quantified, but rather a knowledge of whether significant organic matter is present is required. The recommended test procedure to determine the organic content is presented in Appendix A.

Specific gravity

34. Values for the specific gravity of solids for fine-grained sediments and dredged material are required for determining void ratios, conducting hydrometer analyses, and consolidation testing. Procedures for conducting the specific gravity test are given in Appendix IV of EM 1110-2-1906.[15]

USCS classification

35. When classifying sediment samples, the fine-grained portion which passes the No. 40 sieve should be classified separately from the coarse-grained portion retained on the No. 40 sieve, regardless of which fraction comprises the greatest percentage by weight. Additional information regarding the USCS classification may be found in WES Technical Memorandum No. 3-357.[16]

Sedimentation Tests

36. Sedimentation, as applied to dredged material disposal activities, refers to those operations in which the dredged material slurry is separated into more clarified water and a more concentrated slurry. Laboratory sedimentation tests must provide data for designing the containment area to meet effluent suspended solids criteria and to provide adequate storage capacity for the dredged solids. These tests are based on the gravity separation of solid particles from the transporting water.

37. The sedimentation process can be categorized according to three basic classifications: (a) discrete settling where the particle maintains its individuality and does not change in size, shape, or

density during the settling process; (b) flocculent settling where particles agglomerate during the settling period with a change in physical properties and settling rate; (c) zone settling where the flocculent suspension forms a lattice structure and settles as a mass, exhibiting a distinct interface during the settling process.

38. The important factors governing the sedimentation of dredged material solids are initial concentration of the slurry and flocculating properties of the solid particles. Because of the high influent solids concentration and the tendency of dredged material fine-grained particles to flocculate, either flocculent or zone settling behavior governs sedimentation in containment areas.[8] Discrete settling describes the sedimentation of sand particles and fine-grained sediments at concentrations much lower than those found in dredged material containment areas.

39. The objective of running settling tests on sediments to be dredged is to define, on a batch basis, settling behavior in a large-scale continuous flow dredged material containment area. The tests provide numerical values for the design criteria which can be projected to the size and design of the containment area. It is important that the sediment slurry tested have characteristics in the settling column similar to those it will have in the containment area. This becomes increasingly difficult as the sediment slurry becomes more flocculent and as concentrations increase.

40. Comparative laboratory and field studies indicate that the test procedures using the settling column shown in Figure 3 are satisfactory, with minor procedural changes, for both freshwater and saltwater sediments.[8] Sedimentation of freshwater sediments at slurry concentrations <100 g/ℓ can generally be characterized by flocculent settling properties. As slurry concentrations are increased, the sedimentation process may be characterized by zone settling properties. Salinity >3 ppt enhances the flocculation of dredged material particles. Therefore, the settling properties of saltwater dredged material can usually be characterized by zone settling tests.

41. Samples used to perform sedimentation tests should consist of fine-grained (<No. 40 sieve) material. If coarse-grained (>No. 40 sieve)

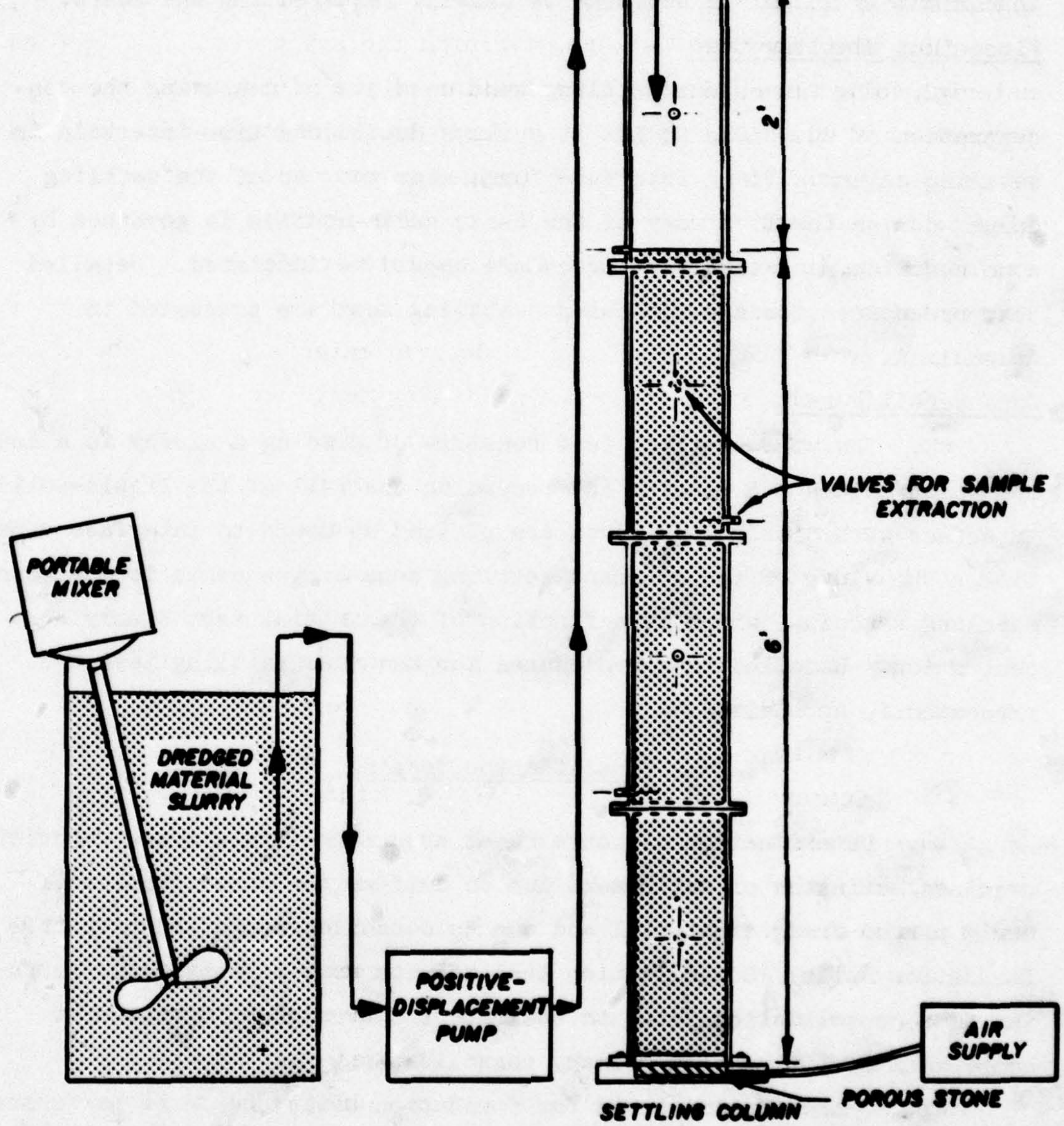


Figure 3. Schematic of apparatus for settling tests (from Montgomery[8])

material present in the sample is less than 10 percent (dry weight basis), separation is not required prior to sedimentation testing. A composite of several sediment samples may be used to perform the tests if this is thought to be more representative of the dredged material. Approximately 15 gal of sediment is usually required for the tests.

Flocculent settling test

42. The flocculent settling test consists of measuring the concentration of suspended solids at various depths and time intervals in a settling column. If an interface forms near the top of the settling column during the first day of the test, sedimentation is governed by zone settling, and that test procedure should be initiated. Detailed test procedures for the flocculent settling test are presented in Appendix A.

Zone settling test

43. The zone settling test consists of placing a slurry in a sedimentation column and reading and recording the fall of the liquid-solids interface with time. These data are plotted as depth to interface versus time. The slope of the constant settling zone of the curve is the zone settling velocity, which is a function of the initial test slurry concentration. Detailed test procedures for the zone settling test are presented in Appendix A.

Consolidation Testing

44. Determination of containment area long-term storage capacity requires estimates of settlement due to self-weight consolidation of newly placed dredged material and due to consolidation of compressible foundation soils. Consolidation test results must be obtained, including time-consolidation data, to estimate the average void ratios at completion of 100 percent primary consolidation.

45. Consolidation tests for foundation soils should be performed as described in EM 1110-2-1906[15] with no modifications. The consolidation testing procedure for sediment samples generally follows that for the fixed ring test for conventional soils, but minor modifications are required.

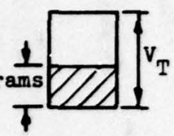
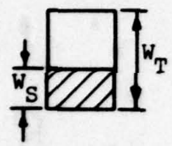
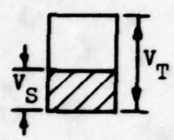
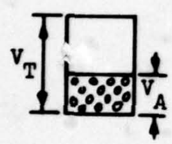
46. Fixed ring consolidometers should be used for consolidation testing of sediment samples due to their fluidlike consistency. The only major modifications for the conventional fixed ring testing procedure concern the sample preparation and the method of loading. Detailed descriptions of test procedures are presented in Appendix A.

Solids Concentration

47. Determinations of solids concentrations are required for settling tests and for samples of containment area influent and effluent taken during the course of containment area management activities. Solids associated with dredged material disposal activities can be divided into total and suspended solids. In practice there has been confusion concerning the method of reporting suspended solids. The terms "concentration in grams per litre," "percent solids by weight," "percent solids by volume," and "percent solids by apparent volume" have been used. These methods of reporting suspended solids concentration are discussed and compared in Table 2. The relationship between percent solids by weight and concentration in grams per litre is illustrated in Figure 4. Suspended solids concentration in grams per litre is used throughout this report. Test procedures for determining suspended solids concentrations are presented in Appendix A.

Table 2

Methods of Reporting Suspended Solids

Method of Reporting Suspended Solids	Weight-Volume Relationship	Method of Computation	Remarks
		Preferred Method	
grams per litre or milligrams per litre	W_S , grams  V_T = 1 litre	$S = \frac{W_S}{V_T}$	Common method for reporting dissolved chemical concentrations. Best method for engineering purposes
		Other Methods	
percent by weight		$S = \frac{W_S}{W_T} 100$	Easy to determine by laboratory test. Does not require value for specific gravity
percent by volume		$S = \frac{V_S}{V_T} 100$	Easy to determine by laboratory test. Requires determination of percent by weight and value for specific gravity
percent by apparent volume	 $V_A = V_S + V_I$	$S = \frac{V_A}{V_T} 100$	Apparent volume determined by settled solids for a bottle or flask. No standardized procedure available. Void ratio of settled solids varies with type of sediment. Can lead to errors because of nonstandard test. Not recommended. Value is meaningless in engineering calculations

Note: W_S = ovendry weight of solid particles
V_T = total volume
W_T = total weight
V_S = volume of solid particles
V_A = apparent volume of settled solids
V_I = volume of interstitial water

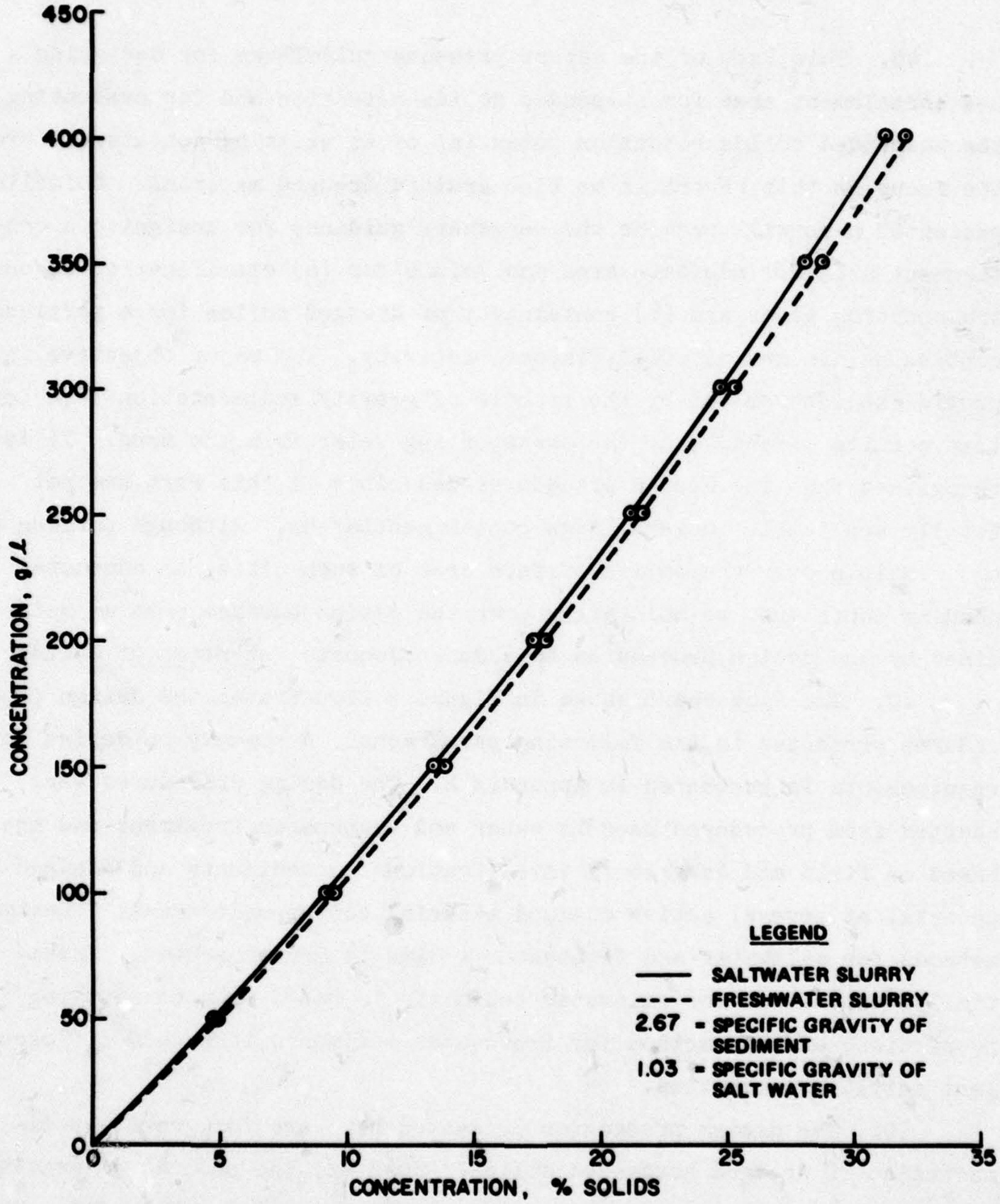


Figure 4. Relationship between concentration in percent solids by weight and in grams per litre (from Montgomery[8])

PART IV: CONTAINMENT AREA DESIGN FOR RETENTION OF SUSPENDED SOLIDS

48. This Part of the report presents guidelines for designing a new containment area for suspended solids retention and for evaluating the suspended solids retention potential of an existing containment area. The focus in this report is on fine-grained dredged material. Guidelines presented here will provide the necessary guidance for designing a containment area for adequate area and volume for (a) clarification of the transporting water and (b) containment of dredged solids for a particular continuous dredged material disposal activity. The major objective is to provide solids removal by the process of gravity sedimentation to a level that permits discharge of the transporting water from the area. It is recognized that the design procedures described in this Part are not totally applicable to very large containment areas. Although ponding is not feasible over the entire surface area of such sites, an adequate ponding depth must be maintained over the design surface area as determined by the design procedures to assure adequate retention of solids.

49. The flow chart shown in Figure 5 illustrates the design procedures presented in the following paragraphs. A summary of design data requirements is presented in Appendix B. The design procedures were adapted from procedures used in water and wastewater treatment and are based on field and laboratory investigations on sediments and dredged material at several active dredged material containment areas.[8] Design methods for saltwater and freshwater sediments are presented. Essentially, the method for saltwater sediments is based on zone settling properties, and the method for freshwater sediments is based on flocculent settling properties.

50. The design procedures presented here are for gravity sedimentation of dredged suspended solids. However, the process of gravity sedimentation will not completely remove the suspended solids from the containment area effluent since wind and other factors can resuspend solids and increase effluent solids concentration. The sedimentation process, with proper design and operation, will normally provide

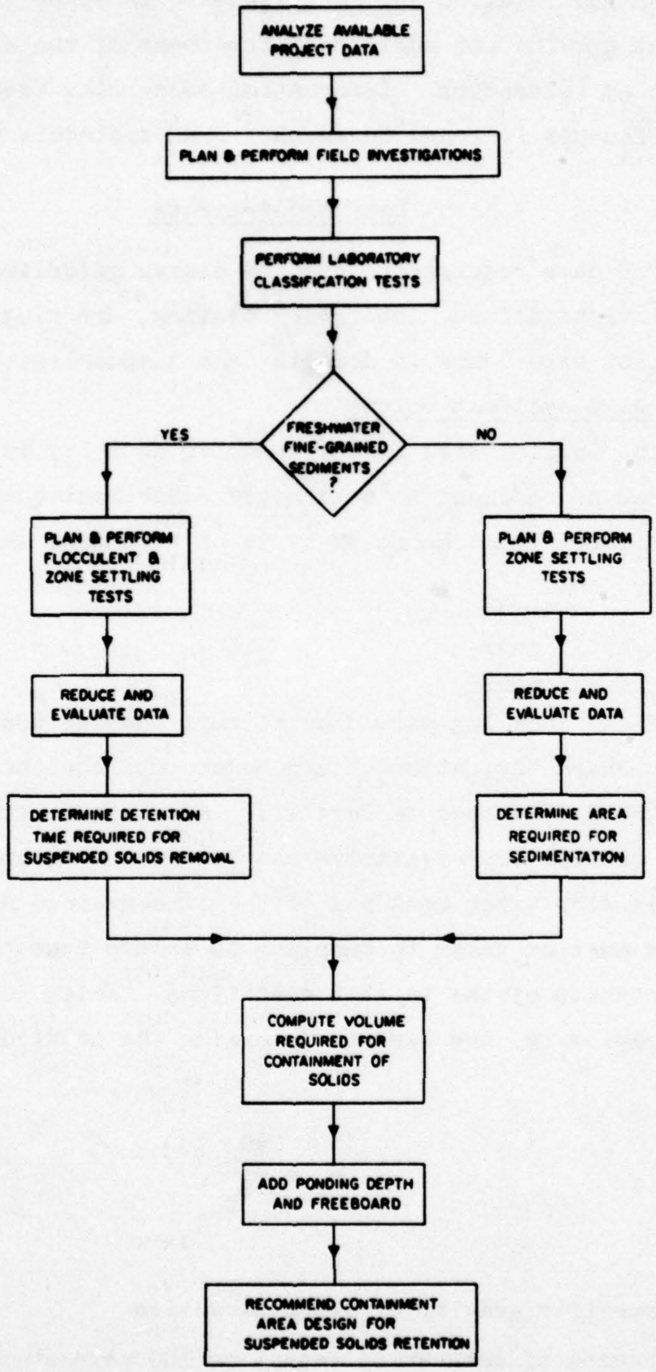


Figure 5. Flow chart of design procedure for fine-grained sediments (from Montgomery[8])

removal of fine-grained sediments down to a level of 1 to 2 g/ℓ in the effluent. If the required effluent standard is lower than this, the designer must provide for additional treatment of the effluent; e.g., flocculation or filtration. Information concerning treatment of containment area effluents is found in another DMRP synthesis report.[17]

Data Requirements

51. The data required to use the design guidelines are obtained from field investigations, laboratory testing, dredging equipment designs, and past experience in dredging and disposal activities.

Estimate in situ sediment volume

52. The initial step in any dredging activity is to estimate the in situ volume of sediment to be dredged. Sediment quantities are usually determined from channel surveys on a routine basis by Corps District personnel.

Determine physical characteristics of sediments

53. Field sampling should be accomplished as described in Part II, and sediment characterization should be accomplished according to the laboratory tests described in Part III. Adequate sample coverage is required to provide representative samples of the sediment. Also required are in situ water contents of the fine-grained maintenance sediments. Care must be taken in sampling to ensure that the water contents are representative of the in situ conditions. Water contents of representative samples w are used to determine the in situ void ratios e_i as follows:

$$e_i = \frac{wG_s}{S_D} \tag{2}$$

where

G_s = specific gravity of sediment solids

S_D = degree of saturation (equal to 100 percent for sediments)

A representative value from in situ void ratios is used later to estimate volume for the containment area. Grain size analyses are used to

estimate the quantities of coarse- and fine-grained material in the sediment to be dredged.

Obtain and analyze pro-
posed dredging and disposal data

54. The designer must obtain and analyze data concerning the dredged material disposal rate. For hydrualic pipeline dredges, the type and size of dredge(s) to be used, average distance to containment area from dredging activity, depth of dredging, and average solids concentration of dredged material when discharged into the containment area must be considered. If the size of the dredge to be used is not known, the largest dredge size that might be expected to perform the dredging should be assumed. The time required for the dredging can be estimated based on past experience. If no data on past experience are available, Figure 6, which shows the relationship among solids output, dredge size, and pipeline length for various dredging depths, should be used. It was developed from data provided for Ellicott dredges.[18] For hopper dredges, an equivalent disposal rate must be estimated based on hopper or barge pump-out rate and travel time involved.

55. Based on these data, the designer must estimate or determine containment area influent rate, influent suspended solids concentration, effluent rate (for weir sizing), effluent concentration allowed, and time required to complete the disposal activity. For hydraulic pipeline dredges, if no other data are available, an influent suspended solids concentration of 145 g/ℓ (13 percent by weight) should be used for design purposes. This value is based on a number of field investigations performed under DMRP research.[8]

Perform laboratory
sedimentation tests

56. The guidelines for sedimentation tests are given in Appendix A. The designer must evaluate the results of salinity tests to determine whether the sediments to be dredged are freshwater or saltwater sediments. If salinity is above 3 ppt, the sediments are classified as saltwater sediments for the purpose of selecting the laboratory sedimentation test.

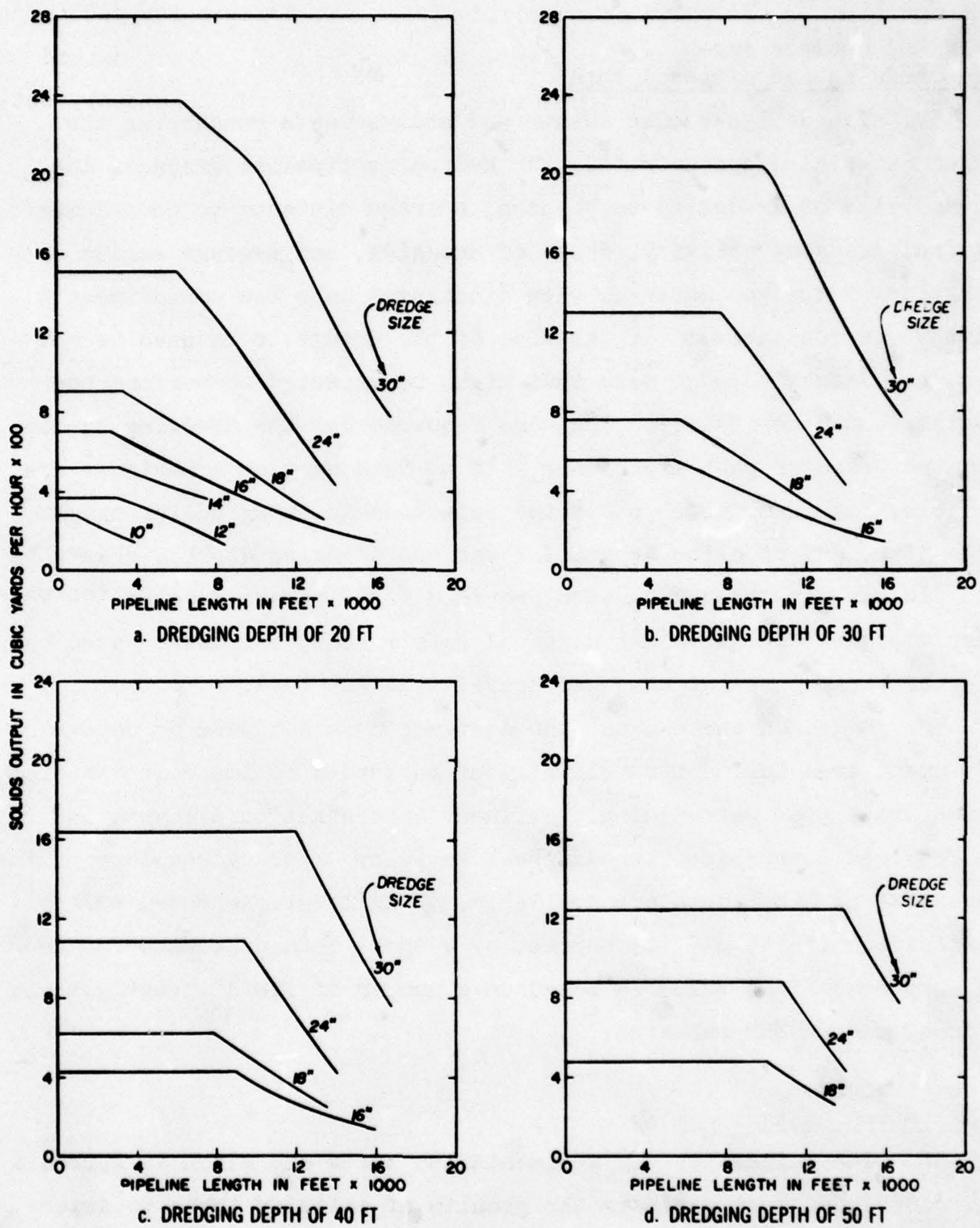


Figure 6. Relationships among solids output, dredge size, and pipeline length for various dredging depths (developed from data provided by Turner[18])

Design Method for Saltwater Sediments

57. The following method provides adequate designs for sedimentation of dredged material from a saltwater environment.[8] This method can also be used for freshwater dredged material if the laboratory settling tests indicate zone settling properties. An example of this design method is presented in Appendix C.

Analyze laboratory data

58. A series of zone settling tests must be conducted as detailed in Appendix A. The results of the settling tests are correlated to determine zone settling velocities at the various suspended solids concentrations. The procedure is as follows:

- a. Develop a settling curve for each test (see Figure A1).
- b. Calculate the zone settling velocity v_s as the slope of the constant settling zone (straight-line portion of curve). The velocity should be in feet per hour.
- c. Plot the v_s versus suspended solids concentration on a semilog plot as shown in Figure A2.
- d. Use the plot developed in c to develop a solids loading versus solids concentration curve as shown in Figure 7.

Compute design concentration

59. The design concentration C_d is defined as the average concentration of the dredged material in the containment area at the end of the disposal activity and is estimated from data obtained from the 15-day column settling tests described in Appendix A. The following steps can be used to estimate average containment area concentrations for each 15-day column settling test. It may be desirable to perform more than one 15-day test. If so, use an average of the values as the design concentration.

- a. Compute concentration versus time for the 15-day settling test. Assume zero solids in the water above the solids interface to simplify calculations.
- b. Plot concentration versus time on log-log paper as shown in Figure C12.
- c. Draw a straight line through the data points. This line should be drawn through the points representing the consolidation zone as shown in Figure A1.

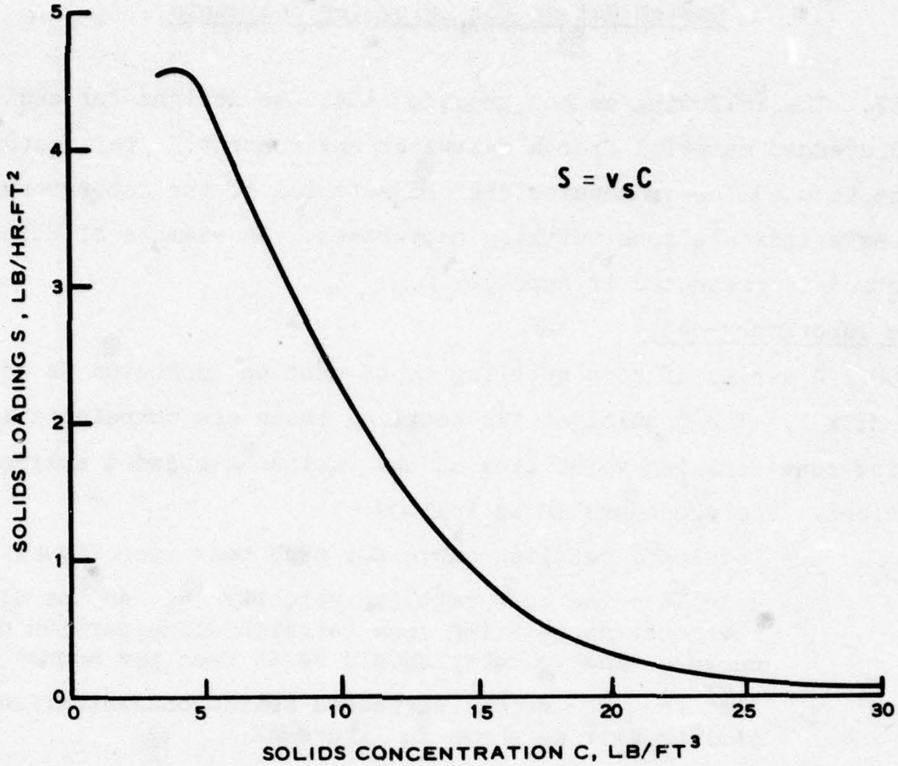


Figure 7. Typical solids loading curve for dredged material (from Montgomery[8])

<u>d</u>. Estimate the time of dredging by dividing the dredge production rate into the volume of sediment to be dredged. Use Figure 6 for estimating the dredge production rate if no specific data are available from past dredging activities.

<u>e</u>. Using the figure developed in steps <u>b</u> and <u>c</u> (see Appendix C), determine the concentration at time t equals one half the time required for the disposal activity determined in step <u>d</u>.

<u>f</u>. Use the value computed in step <u>e</u> as the design solids concentration C_d .

<u>Compute area required for sedimentation</u>

60. Containment areas designed according to the following steps should provide removal of fine-grained sediments such that suspended solids levels in the effluent do not exceed 1 to 2 g/ℓ. The area required for the zone settling process to concentrate the dredged material to the design concentration is computed as follows:

a. Use the design concentration and construct an operating line from the design solids concentration tangent to the loading curve as shown in Figure 8. The design loading is obtained on the y-axis as S_d.

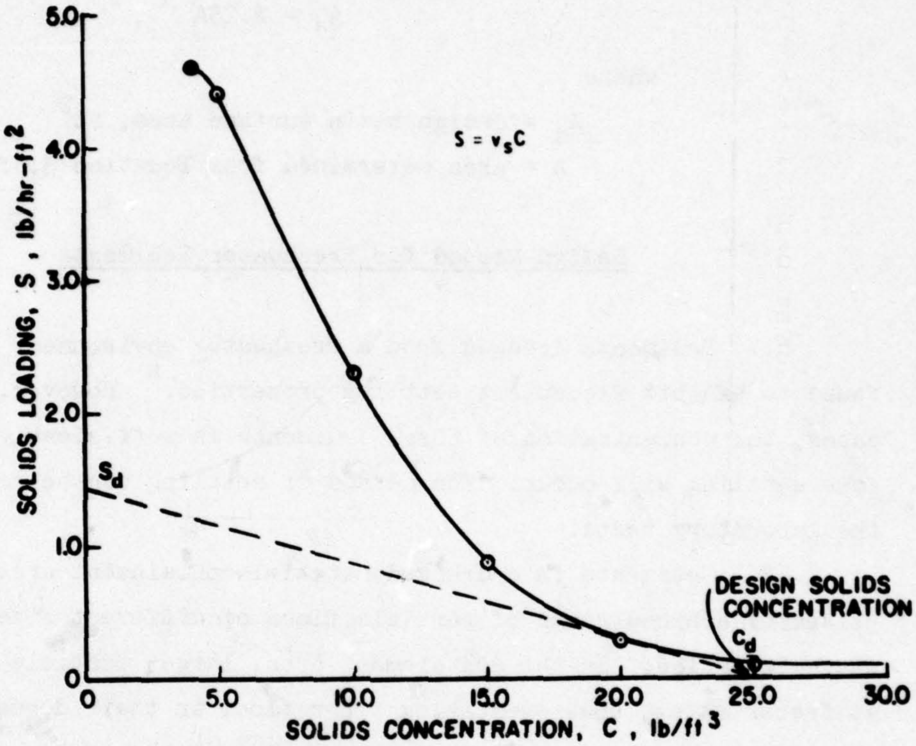


Figure 8. Solids loading curve showing design line (from Montgomery[8])

b. Compute area requirements as

$$A = \frac{Q_i C_i}{S_d} \tag{3}$$

where

A = containment surface area requirement, ft^2

Q_i = influent rate, ft^3/hr ($Q_i = A_p V_d$; assume V_d = 15 fps in absence of data and convert Q_i calculated in cfs to ft^3/hr)

A_p = cross-sectional area of dredge pipeline, ft^2

V_d = velocity of dredge discharge, ft/sec

C_i = influent solids concentration, lb/ft^3 (use 145 g/ℓ or 9.2 lb/ft^3 if no data are available)

S_d = design solids loading, lb/hr-ft^2

c. Increase the area by a factor of 2.25 to compensate for containment area inefficiencies*

$$A_d = 2.25A \tag{4}$$

where

A_d = design basin surface area, ft^2

A = area determined from Equation 3, ft^2

Design Method for Freshwater Sediments

61. Sediments dredged from a freshwater environment have been found to exhibit flocculent settling properties.[8] However, in some cases, the concentration of these sediments is sufficiently high that zone settling will occur. The method of settling can be determined from the laboratory tests.

62. Sediments in a dredged material containment area are comprised of a broad range of particle flocs of different sizes and surface characteristics. In the containment area, larger particle flocs settle at faster rates, thus overtaking finer flocs in their descent. This contact increases the floc sizes and enhances settling rates. The greater the ponding depth in the containment area, the greater is the opportunity for contact among sediments and flocs. Therefore, sedimentation of freshwater dredged sediments is dependent on the ponding depth as well as the properties of the particles.

63. Evaluation of the sedimentation characteristics of a freshwater sediment slurry is accomplished as discussed in Part III. The design steps are as follows (refer to Appendix C for example problems):

a. Step 1. Analyze laboratory data:

(1) Arrange the data from laboratory tests illustrated by Table C1 into the form shown in Table C2 (see Appendix C).

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* Additional information regarding containment area inefficiencies is found beginning in paragraph 70.

(2) Plot these data as shown in Figure 9. The percent of initial concentration by weight for each depth and time is given in Table C2. The solid curved lines represent the concentration depth profile at various times during settling (refer to Figure C1 for more details). Numbers appearing along the horizontal depth lines are used to indicate area boundaries.

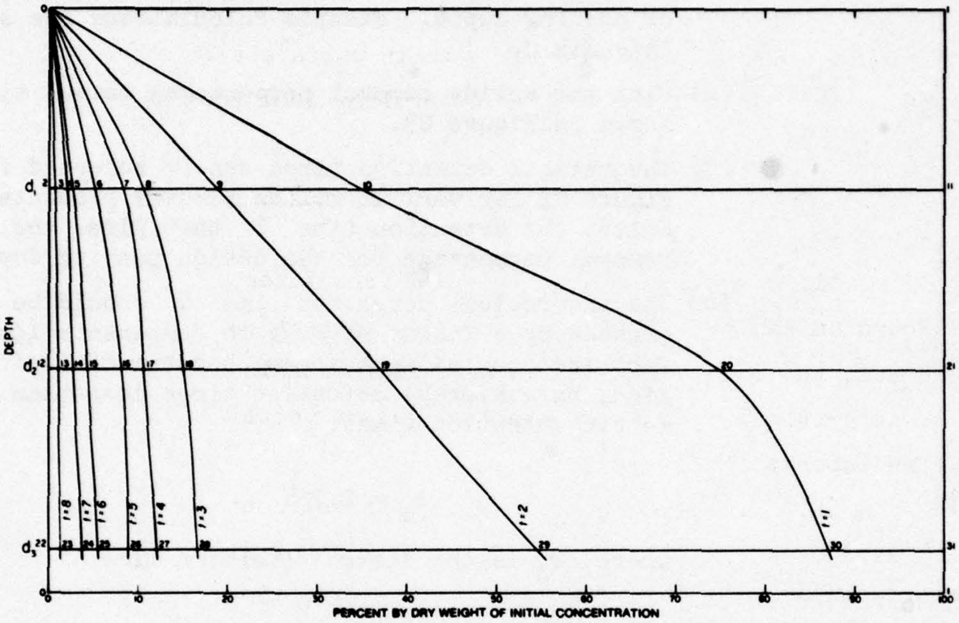

Figure 9. Removal of flocculating dredged material particles (from Montgomery[8])

(3) Compute a design concentration using data from the 15-day zone settling test. Follow the procedure outlined in the design method for saltwater sediments. Refer to Appendix C for an example problem.

b. Step 2. Compute detention time required for sedimentation:

(1) Calculate the removal percentage at depths of 1, 2, and 3 ft for various times using the plot illustrated in Figure 9. The removal percentage for depth d_1 and t equals 1 is computed as follows:

$$R = \frac{\text{Area } 0,\ 10,\ 11,\ 1^{*}}{\text{Area } 0,\ 2,\ 11,\ 1} \times 100 \tag{5}$$

* These numbers correspond to the numbers used in Figure 9 to indicate the area boundaries for the total area down to depth d (0, 2, 11, 1) and the area to the right of the t-equals-1 time line (0, 10, 11, 1).

where R is the removal percentage. Determine these areas by either planimetering the plot or by direct graphical measurements and calculations.

This approach is used to calculate removal percentages for each depth as a function of time. The depths used should cover the range of ponding depths expected in the containment area. This report recommends 2 ft of ponding depth. Example calculations are shown in Appendix C.

(2) Plot the solids removal percentages versus time as shown in Figure C3.

(3) Theoretical detention times can be selected from Figure C3 for various solids removal percentages. Select the detention time T that gives the desired removal percentage for the design ponding depth.

(4) The theoretical detention time T should be increased by a factor of 2.25 to compensate for the fact that containment areas, because of inefficiencies, have average detention times less than volumetric detention times:

$$T_d = 2.25T \tag{6}$$

where T_d is the design detention time.

Volume Requirements for Containment of Solids

64. The procedures outlined in the above paragraphs are aimed at providing containment areas with sufficient areas and detention times to accommodate continuous disposal activities while providing sufficient suspended solids removal to meet effluent suspended solids requirements. Containment areas must also be designed to meet volume requirements for a particular disposal activity. The total volume required of a containment area includes volume for storage of dredged material, volume for sedimentation (ponding depths), and freeboard volume (volume above water surface). Volume required for storage of the coarse-grained (>No. 40 sieve) material must be determined separately as this material behaves independently of the fine-grained (<No. 40 sieve) material.

65. The volume computed in the following steps is the volume occupied by dredged material in the containment area after the completion

of a particular disposal activity. The volume is not an estimate of the long-term needs for multiple-disposal activities. Estimates for long-term storage capacity can be made using the procedures outlined in Part V. The procedures given below can be used to design for volume required for one disposal activity or used to evaluate the adequacy of volume provided by an existing containment area.

a. Compute the average void ratio of the fine-grained dredged material in the containment area at the completion of the dredging operation using the design concentration determined in earlier steps as the dry density of solids. (Note that the design concentration is determined for both the flocculent and the zone settling design procedures.) Use the following equation to determine the void ratio:

$$e_o = \frac{G_s \gamma_w}{\gamma_d} - 1 \tag{7}$$

where

e_o = average void ratio of the dredged material in the containment area at the completion of the dredging operation

γ_w = density of water, g/ℓ

γ_d = dry density of solids, g/ℓ ($C_d = \gamma_d$)

b. Compute the change in volume of the fine-grained channel sediments after disposal in the containment area:

$$\Delta V = V_i \frac{e_o - e_i}{1 + e_i} \tag{8}$$

where

ΔV = change in volume of the fine-grained channel sediments after disposal in the containment area, ft^3

e_i = average void ratio of the in situ channel sediments

V_i = volume of the fine-grained channel sediments, ft^3

c. Compute the volume required by the dredged material in the containment area

$$V = V_i + \Delta V + V_{sd} \tag{9}$$

where

V = volume of the dredged material in the containment area at the end of the dredging operation, ft^3

V_{sd} = volume of sand (compute using 1:1 ratio), ft^3

Estimating Depth of the Containment Area

66. Previous calculations have provided a design area A_d and design detention time T_d required for fine-grained dredged material sedimentation. Equations 7, 8, and 9 are used to estimate volume requirements for the containment area. These volumes are then used, as described in the following paragraphs, to determine the corresponding depth requirements. Throughout the design process, the existing topography of the containment area must be considered since it can have a significant effect on the average depth of the containment area.

Saltwater sediments (zone settling)

67. The following procedure should be used for saltwater sediments:

a. Estimate the thickness of the dredged material at the end of the disposal operation:

$$H_{dm} = \frac{V}{A_d} \tag{10}$$

where

H_{dm} = thickness of the dredged material layer at the end of the dredging operation, ft

V = volume of dredged material in the basin, ft^3 (from Equation 9)

A_d = design surface area, ft^2 (as determined from Equation 4 or use the known surface area for existing sites)

b. Consult with soils design engineers to determine the maximum height allowed for confining dikes.[2] Anticipated settlement of the dikes should also be considered.

c. Add the ponding depth and freeboard depth to H_{dm} to determine the required containment area depth (dike height):

$$D = H_{dm} + H_{pd} + H_{fb} \tag{11}$$

where

D = dike height, ft

H_{pd} = average ponding depth, ft (a minimum of 2 ft is recommended)

H_{fb} = freeboard above the basin water surface to prevent wave overtopping and subsequent damage to confining earth dikes, ft (a minimum of 2 ft is recommended)

d. Compare this value with the allowable dike height (see paragraph 69).

Freshwater sediments
<u>(flocculent settling)</u>

68. The following procedure should be used for freshwater sediments:

a. Compute the volume required for sedimentation:

$$V_B = Q_i T_d \tag{12}$$

where V_B is the containment area volume in cubic feet required for meeting suspended solids effluent requirements.

b. Consult with soils design engineers to determine the maximum height D allowed for confining dikes. In some cases, it might be desirable to use less than the maximum allowed dike height.

c. Compute the design area as the minimum required surface area for storage:

$$A_d = \frac{V}{H_{dm(max)}} \tag{13}$$

where

$$H_{dm(max)} = D - H_{pd} - H_{fb} \tag{14}$$

or set the design area A_d equal to the known surface area for existing sites.

d. Evaluate the volume available for sedimentation near the end of the disposal operation:

$$V^* = H_{pd}A_d \tag{15}$$

where V^* is the volume in cubic feet available for sedimentation near the end of the disposal operation.

e. Compare V^* and V_B. If the volume required for sedimentation is larger than V^*, the containment area will not meet the suspended solids effluent requirements for the entire disposal operation. The following three measures can be considered to ensure that effluent requirements are met: (1) increase the design area A_d, (2) operate the dredge on an intermittent basis when V^* becomes less than V_B or use a smaller size dredge, and (3) provide for posttreatment of the effluent to remove solids.

f. Estimate the thickness of dredged material at the end of the disposal operation using Equation 10. A_d is determined using step c above.

g. Determine the required containment area depth using Equation 11.

h. Compare this depth with the maximum allowable dike height (see paragraph 69).

69. At most containment areas, the foundation soils are soft. Such foundations limit the heights of confining earth dikes that can be economically constructed. Therefore, soils design engineers must be consulted to determine the maximum dike heights that can be constructed. If the maximum dike height allowed by foundation conditions is less than the containment area depth requirement determined from Equation 11, the design area A_d must be increased until the depth requirement can be accommodated by the allowable dike height; the thickness of the dredged material layer must also be decreased.

Factors Influencing Containment Area Efficiency

70. The design guidelines presented in the preceding sections were developed on the basis of laboratory data. Although these data provide

a basis for the design of full-scale, continuous dredging operations, they must be modified to consider actual performance characteristics of dredged material containment areas. A correction factor of 2.25 was applied to the designs presented earlier to account for the "nonideal" behavior of the full-scale containment area (i.e., scale-up and operation problems). This factor was based on dye tracer investigations performed at active containment areas with physical characteristics similar to the containment area shown in Figure 1.[8,9] From these studies, a correction factor of 2.25 applied to area and detention time requirements appears reasonable. However, this factor can be increased or decreased by the designer if data are available to justify a different correction factor.

71. Short-circuiting is by far the most common and significant fault with dredged material containment areas. The overall effect of short-circuiting is to reduce the effective residence time of a major portion of the flow. This has a serious adverse effect, particularly on sedimentation of freshwater dredged material because of its flocculent nature. Short-circuiting can be caused by insufficient ponding depth, improper location of the dredged material inlet pipeline in relationship to the discharge weir, topography, or vegetation in the basin. All of these cause an improper distribution of velocity vectors resulting in shortened detention periods and increased velocities with resultant scouring of settled solids.

Short-circuiting

72. Ponding depth. Ponding depth is illustrated in Figure 1. Essentially, it is the depth of ponded water above the solids interface required for sedimentation in a containment area. Insufficient ponding depth is a major cause of short-circuiting. Basically, ponding depths should be as great as possible to provide longer detention times, minimize flow velocities, and maximize protection against resuspension and discharge of bottom sediments. Figure 10 is a photograph of a containment area experiencing short-circuiting as a result of insufficient ponding depth. The inefficient flow patterns in this containment area significantly reduce the effective sedimentation area and detention

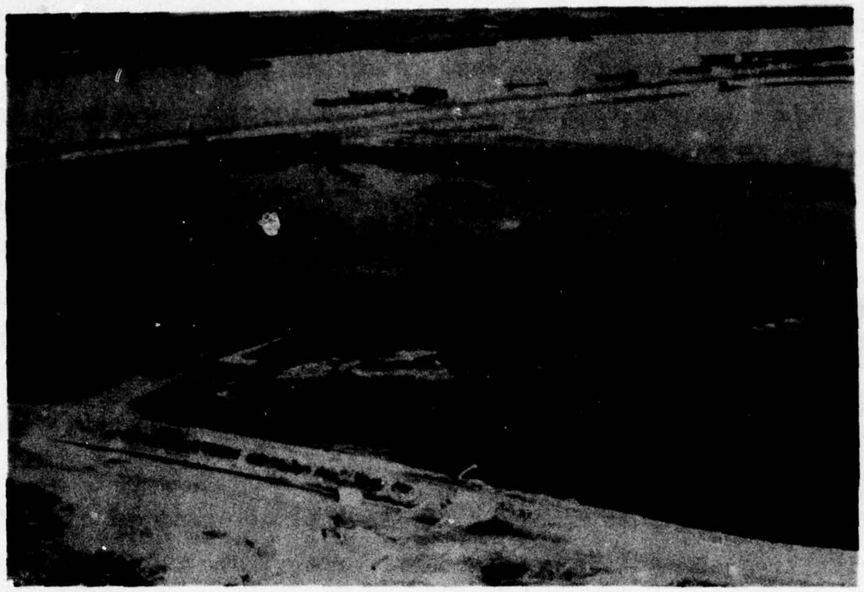

Figure 10. Containment area with insufficient ponding depth and resultant short-circuiting (from Montgomery[8])

time needed for removal of suspended solids.

73. There has been reluctance in the past to pond water during disposal activities because of concern about potential dike failures. This concern is eliminated when the dikes are properly designed and constructed.[2]

74. Providing adequate ponding depth during disposal activities is an operational as well as a design function. Proper designs can be negated by improper containment area operation such as maintaining insufficient ponding depth. A minimum ponding depth of 2 ft is recommended for sedimentation of solids during a continuous disposal activity. Lesser ponding depths can be tolerated when the dredge is operated on an intermittent basis. Ponding depths greater than 2 ft may be required for efficient weir operation. Refer to Part VI for guidance on weir design and operation.

75. <u>Spur dikes.</u> Spur dikes can be used to minimize short-circuiting and improve dredged material containment area efficiency.[9] In many cases, spur dikes are an economical method for modifying containment areas to provide efficient flow patterns, increase effective

length-to-width ratios, minimize prevailing wind effects, and/or prevent short-circuiting when the inlet and weir must be located on the same side of the containment area.

76. Examples of longitudinal and transverse spur dike configurations are shown in Figure 11. No definite guidelines are available for

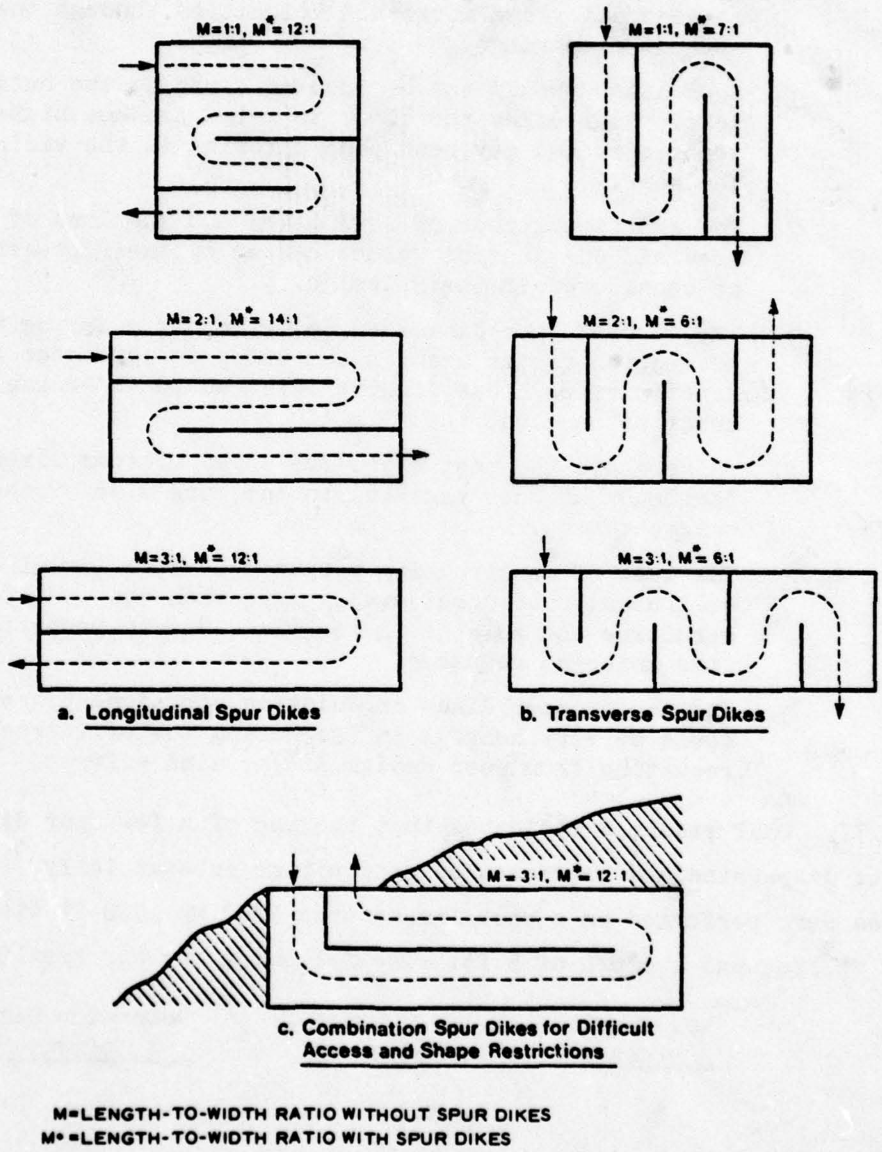

Figure 11. Examples of longitudinal and transverse spur dike configurations (from B. J. Gallagher and Co.[9])

placement of spur dikes. The primary objective is to increase the length-to-width ratio of the containment area. The following general guidance is presented for design of spur dikes for a containment area.

a. One or two spur dikes should usually be sufficient.

b. The length of spur dikes should be about three fourths the length of the parallel side of the containment area. Spur dikes longer than this may result in excessive flow concentration and increased velocities through the spur dike openings.

c. Spur dikes should not be located close to the outlet weir. Spur dikes too close to weirs produce higher velocities and may resuspend material in the vicinity of the weir.

d. The additional cost of spur dikes and the loss of surface area and containment volume caused by their presence must be considered in their design.

e. The cost of spur dikes can be offset by reducing the correction factor used in computing design areas and detention times. Use of spur dikes would allow smaller areas to be used.

f. In general, the most effective types of spur dikes are longitudinal ones parallel to the long side of the containment area.

g. The cost of constructing a spur dike (per lineal foot) will usually be considerably less than the cost for constructing the main perimeter dike, due to proportionally less material required.

h. The use of spur dikes in existing containment areas could be very helpful in increasing low efficiencies resulting from poor design and/or wind effects.

77. DMRP research indicates that the use of a few spur dikes decreases dispersion and increases detention time substantially.[9] Model studies were performed on a containment area 3000 by 1500 ft with a flow of 70 ft^3/sec and a depth of 5 ft. The following are the results:

No. Spur Dikes	Hours	Detention Time % Increase
0	31	--
1	41.5	34
3	45	45

The dispersion curve was sharpened by the addition of three spur dikes to more closely resemble plug flow.

78. Weir placement. Short-circuiting and dead zones can be reduced by the judicious placement of weirs. The shaded area in Figure 12a

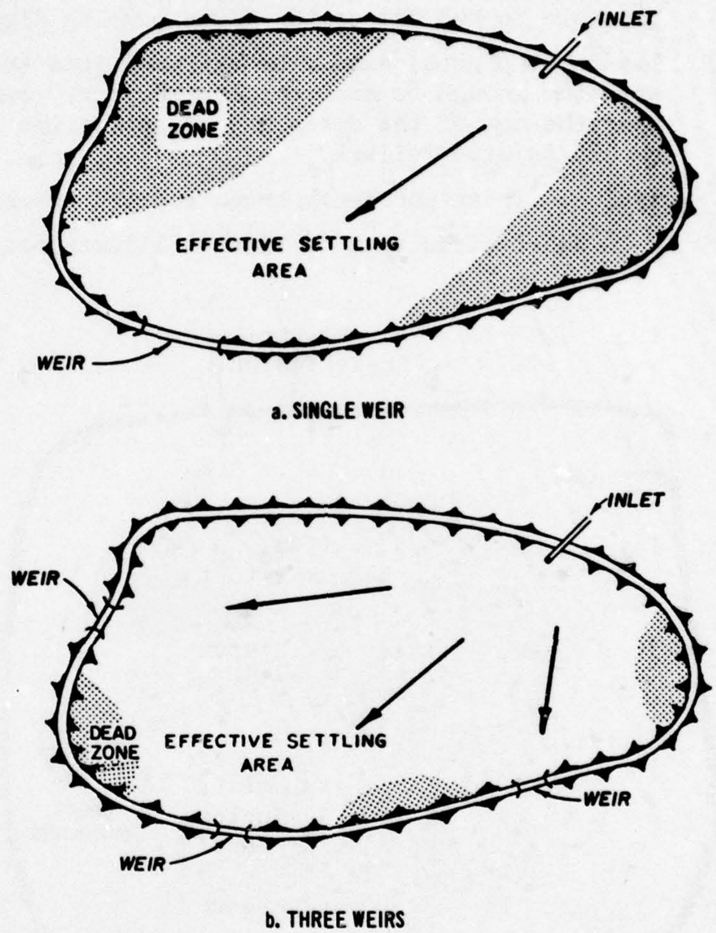

Figure 12. Effect of weir location on short-circuiting (from Walski and Schroeder[19])

indicates dead zones caused by use of one weir. By use of three weirs (each with length one third that of the weir in Figure 12a) the dead zones may be reduced (as shown in Figure 12b). Weir locations should always be selected as far as practicable from anticipated locations of the inlet pipe to increase effective detention time. The following guidelines for location of weirs and inlets are recommended:

a. A weir structure(s) should be located at low spots on the perimeter of the containment area as near as practical to the body of water to which effluent is to be discharged.

b. After the weir location has been specified, the inlet pipe(s) should be located on the perimeter as far from the weir(s) as possible, while being located as near as possible to the dredge to reduce pumping distance.

c. The inlet pipe(s) should be extended into the containment area far enough to ensure that the slurry cannot flow near the toe of the dikes and cause erosion that could result in dike failure.

79. Vegetation. Trees and heavy brush located in containment areas can result in short-circuiting of flow as illustrated in Figure 13.

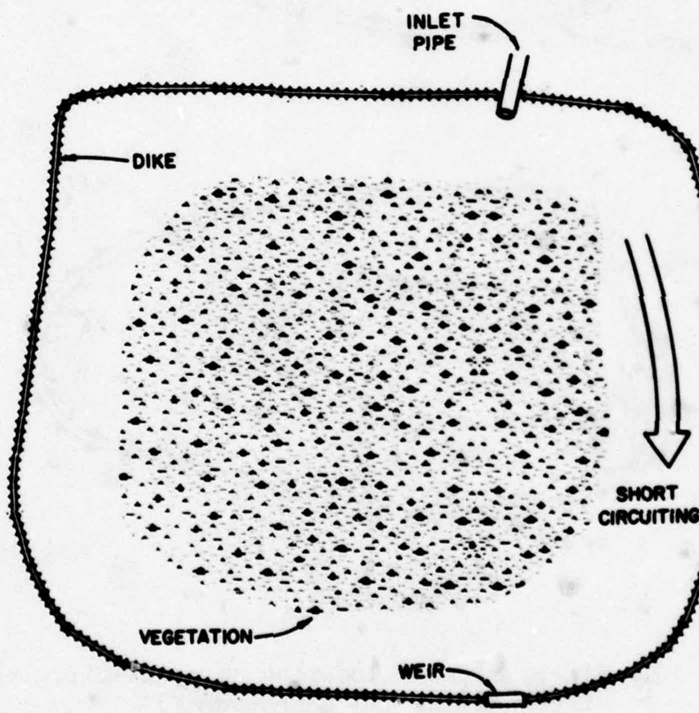

Figure 13. Short-circuiting caused by vegetation in containment area (from Walski and Schroeder[19])

Serious short-circuiting problems were observed at several active containment areas during research for the DMRP.[19] Vegetation such as weeds and grasses may or may not be beneficial in containment areas. In some cases, such vegetation may act as a filter to improve effluent quality.

However, if the vegetation is too dense, it may cause short-circuiting and/or unwanted buildup of solids near the discharge pipe.

Shape of containment area

80. In practice, economic constraints and land use patterns generally govern the geometry of the land that can be acquired for use as a dredged material containment area. The shape of the containment area should be such that the enclosed volume is effectively used for sedimentation purposes. Economic considerations promote large square-shaped containment areas or areas with low length-to-width ratios. However, the hydraulic efficiencies of these containment areas are low unless modified by internal spur dikes. Containment areas with higher length-to-width ratios are more efficient than square- or irregular-shaped areas but cost more to construct.

81. The following recommendations are made for designing the shape of dredged material containment areas.

a. Site selection:

(1) For design purposes, evaluate the shape and location of the proposed containment area on the basis of economics and efficiency for sedimentation.

(2) Square-shaped areas should be considered first. Use spur dikes to increase the efficiency for sedimentation.

(3) Long, narrow strips of land parallel to waterways and near the dredging activity should be the next choice.

b. Shape and internal configuration:

(1) Design the containment area with a high length-to-width ratio (≥ 4).

(2) If economic factors control, resulting in a large square-shaped containment area, use spur dikes to increase the length-to-width ratio.

(3) If economic factors do not control and sufficient land is available, design the containment area in the shape of a rectangle with a length-to-width ratio equal to or greater than 4.

PART V: ESTIMATION OF LONG-TERM STORAGE CAPACITY

82. If the containment area is intended for one-time use, as in the case of some new work projects, estimates of long-term storage capacity are not required. However, containment areas intended for use in conjunction with recurring maintenance work must be sized for long-term storage capacity over the service life of the facility.

83. This Part of the report presents guidelines for estimating long-term containment area storage capacity. The storage capacity is defined as the total volume available to hold additional dredged material and is equal to the total unoccupied volume minus the volume associated with ponding requirements and freeboard requirements. The estimation of long-term storage capacity is an important consideration for long-term planning and design of new containment areas or evaluation of the remaining service life of existing sites.

84. After dredged material is placed within a containment area, it undergoes sedimentation and self-weight consolidation, resulting in gains in storage capacity. The placement of dredged material also imposes a loading on the containment area foundation; therefore, additional settlement may result due to consolidation of compressible foundation soils. Settlement due to consolidation is therefore a major factor in the estimation of long-term storage capacity. Since the consolidation process is slow, especially in the case of fine-grained materials, it is likely that total settlement will not have taken place before the containment area is required for additional placement of dredged material. For this reason, the time-consolidation relationship is also an important consideration in estimating long-term containment area storage capacity. Settlement of the containing dikes also significantly affects the available storage capacity and should be considered.

85. Guidelines for estimation of gains in long-term capacity due to settlement within the containment area are based on the fundamental principles of consolidation theory modified to consider the self-weight consolidation behavior of newly placed dredged material. The guidelines are presented in the following paragraphs; illustrative examples,

including example calculations, are presented in Appendix C. The variable nature of the materials involved and the range of conditions which may exist at any containment area dictate that these guidelines be applied using sound engineering judgment by personnel knowledgeable of the principles of soil mechanics.

Settlement Due to Consolidation

Dredged material

86. Settlement due to self-weight consolidation of dredged material may be estimated by considering the change of void ratio due to the self-weight loading. The average load is assumed to act at midheight of the dredged material layer and is equal to the effective stress due to buoyant weight of the overlying material.

87. The following expression can be used to compute the average effective stress acting at the midheight of the dredged material layer:

$$\overline{p}_f = \frac{H_{dm}(\gamma_w)\dfrac{G_s - 1}{1 + e_o}}{2} \qquad (16)$$

where

$\overline{p}_f$ = average effective stress acting at midheight of the layer of dredged material solids, lb/ft^2

γ_w = density of water = 62.4 lb/ft^3

88. The initial thickness of the dredged material layer H_{dm} is a function of the surface area in use and the volume occupied by the dredged material at the completion of the dredging operation (as determined in Part IV). When evaluating the remaining long-term storage capacity of existing sites, the surface area is known, and the initial lift thickness for a given disposal operation may be determined directly. However, design of new containment areas to accommodate a given long-term storage capacity requires that the surface area be determined by trial as illustrated by the example in Appendix C.

89. The change in thickness of the dredged material layer due to primary consolidation can be estimated using the following expression:

$$\Delta H = H_{dm} \frac{e_o - e_f}{1 + e_o} \quad (17)$$

where

ΔH = change in thickness of the layer at the completion of primary consolidation, ft

e_f = average void ratio at the completion of primary consolidation

90. The void ratio e_f corresponding to the effective stress $\bar{p}_f$ can be determined using an e-log p relationship as shown in Figure 14

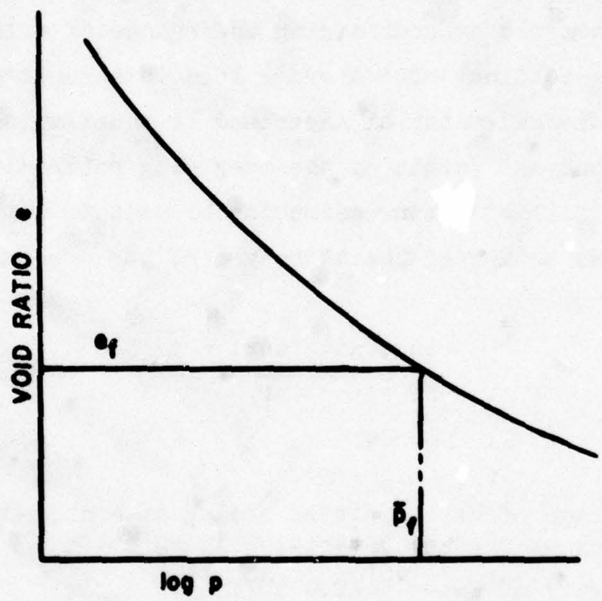

Figure 14. Illustrative plot of void ratio versus log of pressure for newly placed dredged material

obtained from the dredged material consolidation test performed as discussed in Appendix A. This void ratio is representative of the average void ratio of the dredged material layer at the completion of primary consolidation. Since the time required to reach ultimate consolidation may be years, the dredged material layer will probably not reach the final thickness before the containment area is again required for dredged material placement. Therefore, a relationship for the time-rate of consolidation must be developed as described in paragraphs 96-99

before the available storage capacity can be estimated.

Foundation soil(s)

91. Settlement of the foundation soil(s) may be estimated by using conventional soil mechanics principles. Specific considerations related to containment areas are discussed below. Additional guidance for the determination of foundation consolidation and computation of settlement is given in EM 1110-2-1904.[20]

92. Settlement of the containment area foundation soil(s) is caused by the increased load imposed on these compressible soils by placement of dredged material. The magnitude of this load is dependent upon the volume of dredged material deposited and the water table conditions existing during and following the disposal operation.

93. The total load on the foundation soils caused by placement of dredged material is initially dependent upon the weight of the layers of solids and the ponded water maintained in the containment area during the disposal operation. Following disposal, the ponded water should be decanted, thus reducing the total load. However, the groundwater table conditions existing during and after disposal (i.e., perched or continuous) will dictate the effective loading placed upon foundation soils. An evaluation of the groundwater conditions must be made based on the foundation stratification and initial water table conditions as revealed by the field exploration program. Since the imposed loads are uniformly distributed over an area which is usually large compared to the depth of the compressible layers, the increase in loading Δp on the foundation may be considered as constant for full depth.

94. The ultimate settlement of each foundation soil stratum for a given load Δp can be estimated by the expression:

$$\Delta H = \frac{e_1 - e_2}{1 + e_1} (H) \tag{18}$$

where

ΔH = change in thickness of the layer at the completion of primary consolidation, ft

e_1 = initial void ratio of the soil layer at pressure p_1

e_2 = final void ratio of the soil layer at pressure $p_2 = p_1 + \Delta p$

H = initial thickness of the layer, ft

95. The values of e_1 and e_2 may be obtained as shown in Figure 15 using the pressure-void ratio relationship developed from the

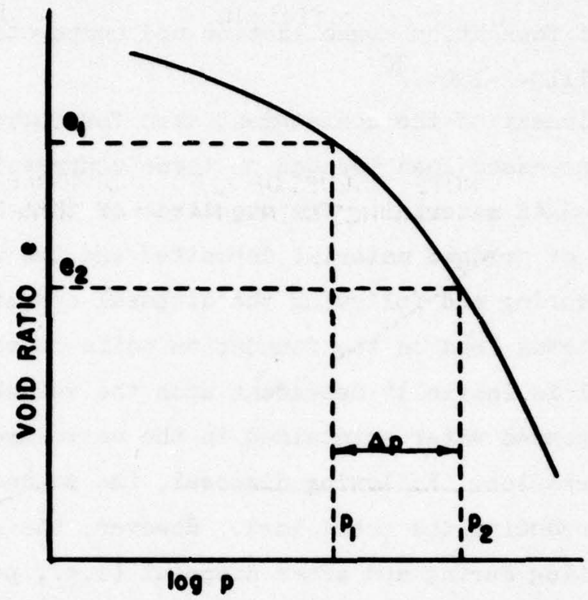

Figure 15. Illustrative plot of void ratio versus log of pressure for foundation soils

consolidation tests on foundation soils using the average loads p_1 and p_2 existing before and after the disposal operation. The total settlement of the foundation under a particular Δp may be determined by summing the settlements of the individual soil strata.

Time-Rate of Consolidation

96. Since the consolidation of dredged material and compressible foundation soils may require significant periods to reach completion, the time-rate of consolidation must be considered so that the available storage capacity at any time can be determined. The procedure for estimating the time-rate of consolidation described in this section generally follows those methods found in EM 1110-2-1904[20] and is applicable to both self-weight consolidation of dredged material and consolidation of

foundation soils. Values for the coefficient of consolidation c_v may be determined from the consolidation-time data using the Log-Time Method as described in EM 1110-2-1904.[20] The values for c_v should be determined for each consolidation pressure used in the consolidation tests, and a plot of c_v versus consolidation pressure should be constructed as shown in Figure 16. The coefficient of consolidation corresponding

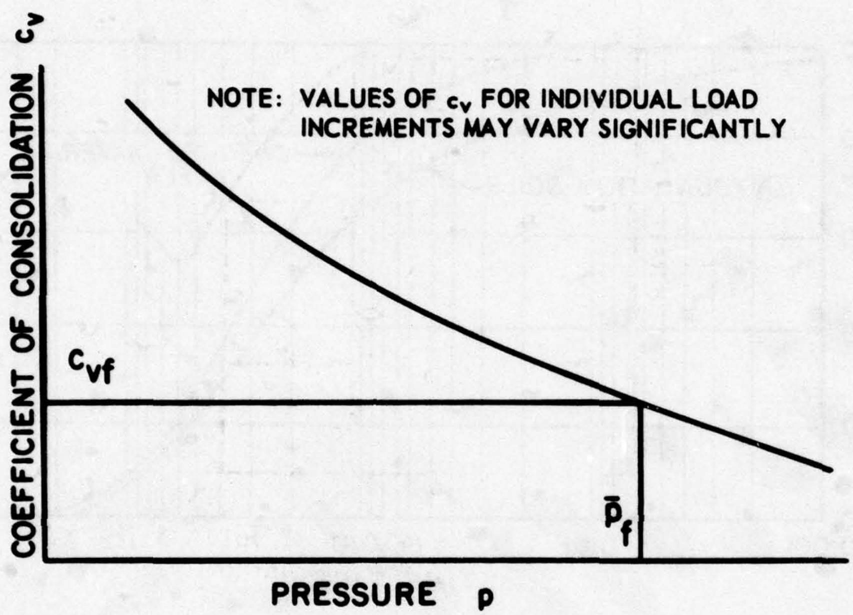

Figure 16. Illustrative relationship of the coefficient of consolidation versus consolidation pressure

to the average effective stress at midheight of the layer under consideration c_{vf} can then be determined using the plot.

97. Time required for the layer to reach various percentages of ultimate consolidation U can be estimated using the following expression:

$$t_u = \frac{T_u H_{dm}^2}{c_{vf}} (144) \tag{19}$$

where

t_u = time to reach degree of consolidation U , min

T_u = time factor for degree of ultimate consolidation U (see Figure 17).

Time factors for various percentages of total consolidation are shown in Figure 17. Values for H_{dm} will be equal to the total layer thickness assuming single drainage or one half the layer thickness assuming double drainage.

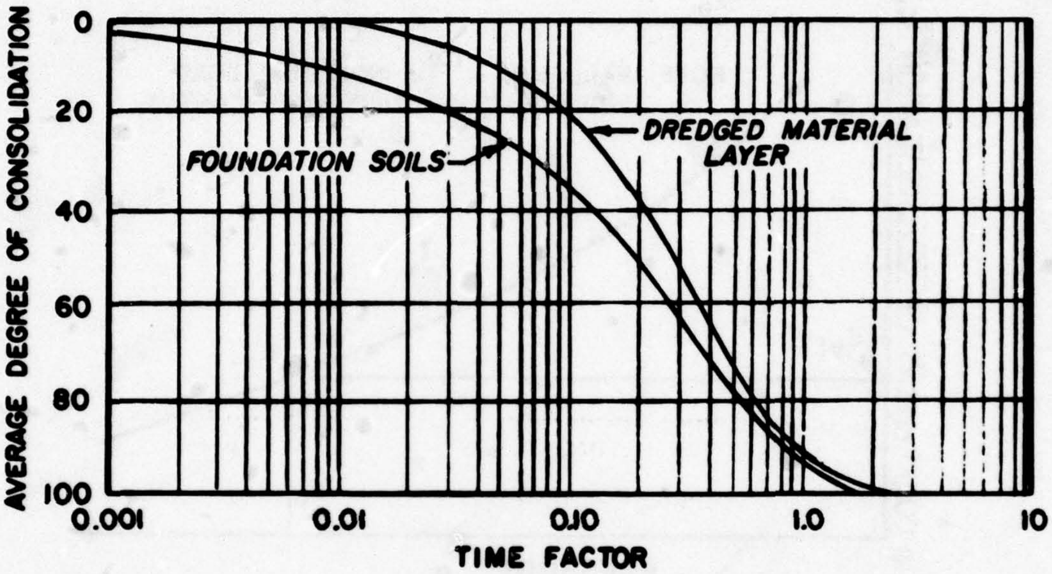

Figure 17. Time factors for consolidation analysis (adapted from NAVFAC DM-7[21])

98. The settlement of the layer at time t_u may be estimated by the expression:

$$\Delta H_{tu} = \frac{U}{100} (\Delta H) \tag{20}$$

where

ΔH_{tu} = settlement of the layer at time t_u, ft

99. Plots of the time-rate of consolidation may then be constructed for each layer as shown in Figure 18. By using these curves, a long-term storage capacity versus time relationship for a single lift can be estimated. The effects of surface drying on storage capacity must be separately determined as described by Haliburton.[3]

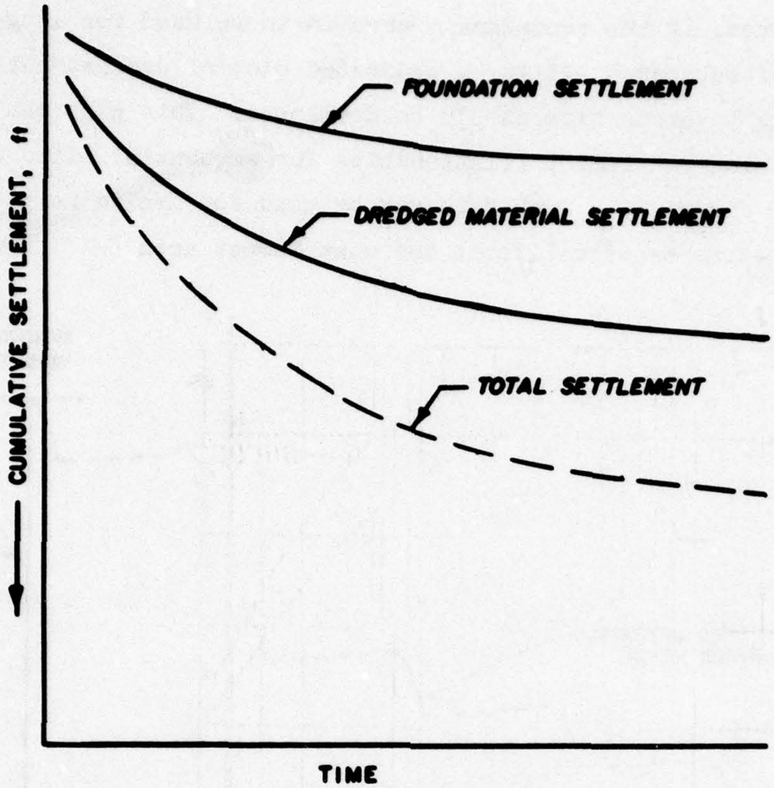

Figure 18. Illustrative time-consolidation relationships

Placement of Sequential Lifts of Dredged Material

100. Estimates of settlement caused by placement of subsequent lifts of dredged material should consider the continued consolidation of previously placed lifts and additional foundation consolidation. This is most effectively done by considering the previously placed dredged material layer as an added foundation soil layer.

Storage Capacity-Time Relationship

101. The estimated time-settlements due to dredged material and foundation consolidation may be combined to yield a time-total settlement relationship for a single lift as shown in Figure 18. These data are sufficient for estimation of the remaining capacity in the short

term. However, if the containment area is to be used for long-term placement of subsequent lifts, a projected plot of dredged material surface height versus time should be developed. This plot can be developed using time-settlement relationships for sequential lifts combined as shown in Figure 19. Such data may be used for preliminary estimates of the long-term service life of the containment area.

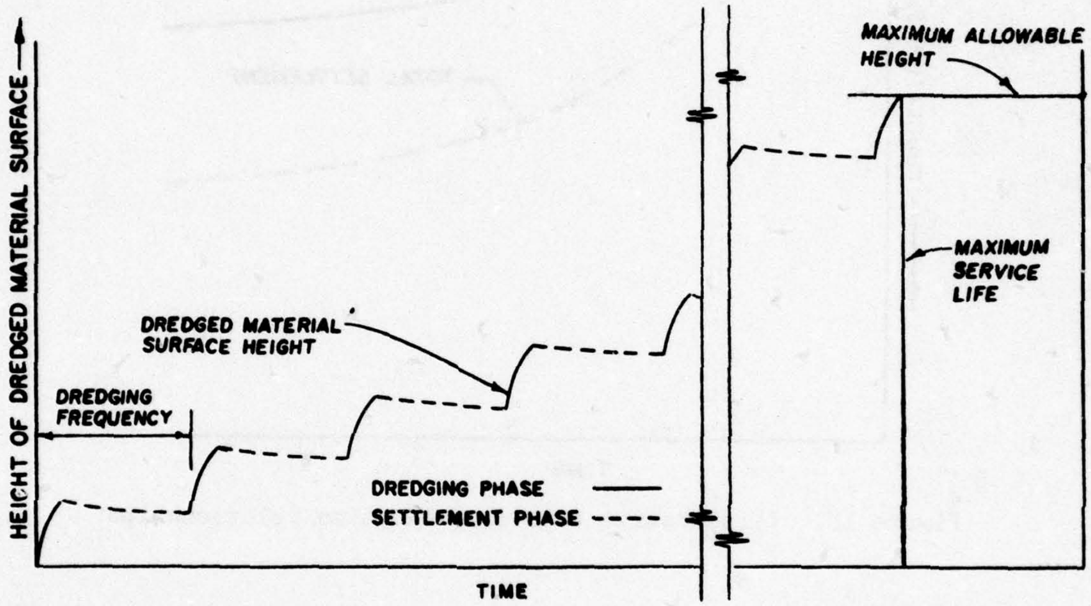

Figure 19. Projected surface height for determination of containment area service life

102. The maximum dike height as determined by foundation conditions or other constraints and the containment surface area will dictate the maximum available storage volume. The increases in dredged material surface height during the dredging phases and the decreases during settlement phases correspond to respective decreases and increases in remaining containment storage capacity, shown in Figure 20. Projecting the relationships for surface height or remaining capacity to the point of maximum allowable height or exhaustion of remaining capacity, respectively, will yield an estimate of the containment area service life. Gains in capacity due to anticipated dewatering or material removal should also be considered in making the projections.

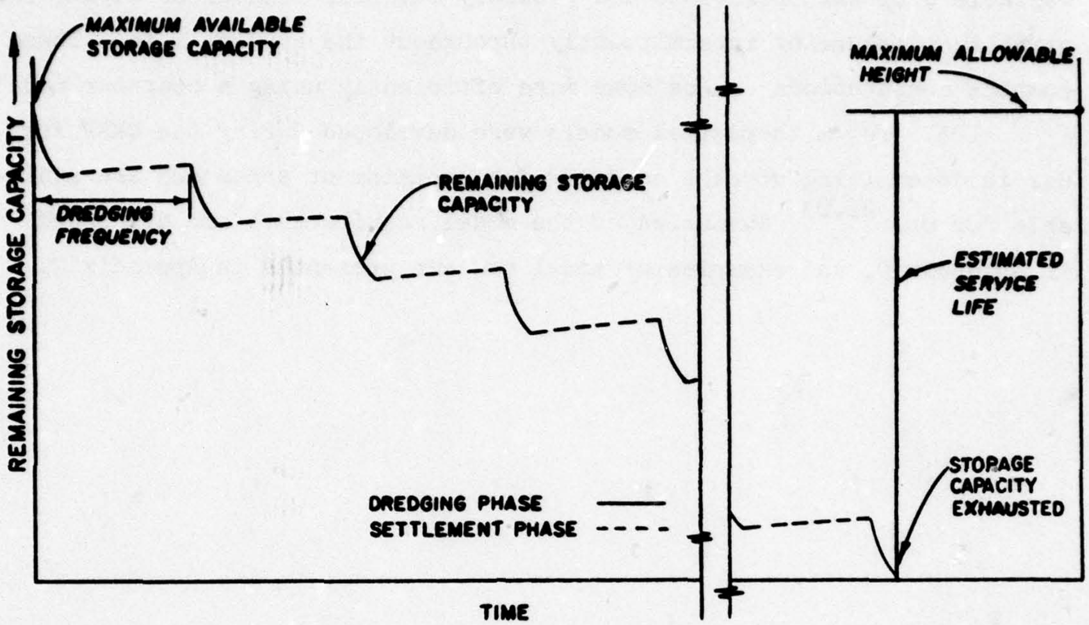

Figure 20. Projected storage capacity for determination of containment area service life

103. The complex nature of the consolidation-time relationships for multiple lifts of compressible dredged material and the changing nature of the resulting loads imposed on compressible foundation soils will not allow accurate projections of remaining storage capacity over long time periods. For this reason, such long-range projections should be used strictly for planning purposes. Accuracy can be greatly improved by periodically updating the estimates every few years using data from newly collected samples and laboratory tests. Observed field behavior should also be routinely recorded and used to refine the projections.

Mathematical Models

104. The use of computer models can greatly facilitate the estimation of storage capacity for containment areas. Although the computations for simple cases can be easily and quickly done by hand, the analyses may require computations for a multiyear service life with

variable disposal operations and possibly material removal or dewatering operations occurring intermittently throughout the service life. These complex computations can be done more efficiently using a computer model.

105. Two mathematical models were developed during the DMRP for use in determining storage capacity for containment areas and are available for use.[22,23] Summaries of the model requirements are discussed in Appendix D, and examples of model use are presented in Appendix C.

PART VI: WEIR DESIGN AND OPERATION

106. The purpose of the weir structure is to regulate release of ponded water from the containment area. Proper weir design and operation can control resuspension and withdrawal of settled solids. The effects of weir location on hydraulic efficiency of containment areas are described in Part IV.

Guidelines for Weir Design

Weir design and containment sizing

107. Weir design is based on providing the capability for selective withdrawal of the clarified upper layer of ponded water. The weir design guidelines as developed in the following paragraphs are based on the assumption that containment area designs have provided sufficient area and volume for sedimentation and that short-circuiting is not excessive.

Effective weir length and ponding depth

108. Ponding depth and effective weir length are the two most important parameters in weir design. The weir design guidelines presented in this section allow evaluation of the trade-off involved between these parameters.

109. In order to maintain acceptable effluent quality, the upper layers containing low levels of suspended solids should be ponded at depths greater than the depth of the withdrawal zone, the area through which fluid is removed for discharge over the weir as shown in Figure 21. The size of the withdrawal zone also affects the approach velocity of flow toward the weir.

110. The weir shape or configuration affects the dimensions of the withdrawal zone and consequently the approach velocity. Since weirs do not extend across an entire side of the containment area, flow concentrations of varying degree occur near the weir, resulting in possible

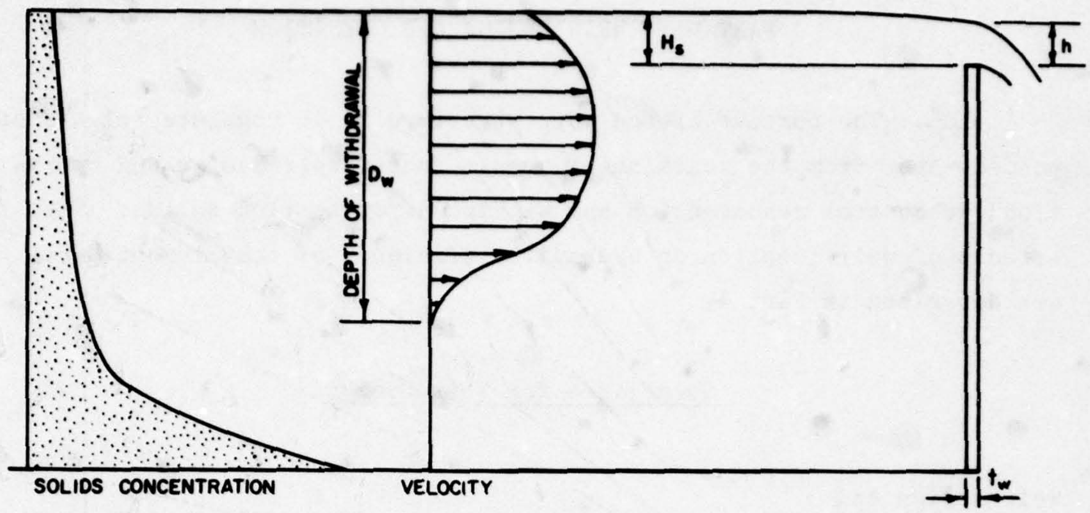

Figure 21. Conceptual illustration of withdrawal depth and velocity profile

resuspension of solids. Longer effective weir lengths result in less concentration of flow. The minimum width through which the flow must pass may be termed the effective weir length L_e .

111. The relationship between effective weir length and ponding depth for various conditions of inflow and effluent suspended solids is illustrated by the nomographs for freshwater clays and for silts and saltwater clays in Figures 22 and 23, respectively. The nomographs were developed based on the principles of selective withdrawal assuming zero suspended solids at the surface and have been verified by only limited field data.[19]

Design procedure

112. To design a new weir to meet a given effluent suspended solids level, the following procedure should be used:

a. Use the following guide to select the appropriate nomograph based on the expected salinity during the dredging operation and the USCS classification of the fine-grained portion of the sediment:

Salinity, ppt	Clay (CL, CH)	Silt (ML, MH)
<1	Freshwater nomograph (Figure 22)	Saltwater nomograph (Figure 23)

(Continued)

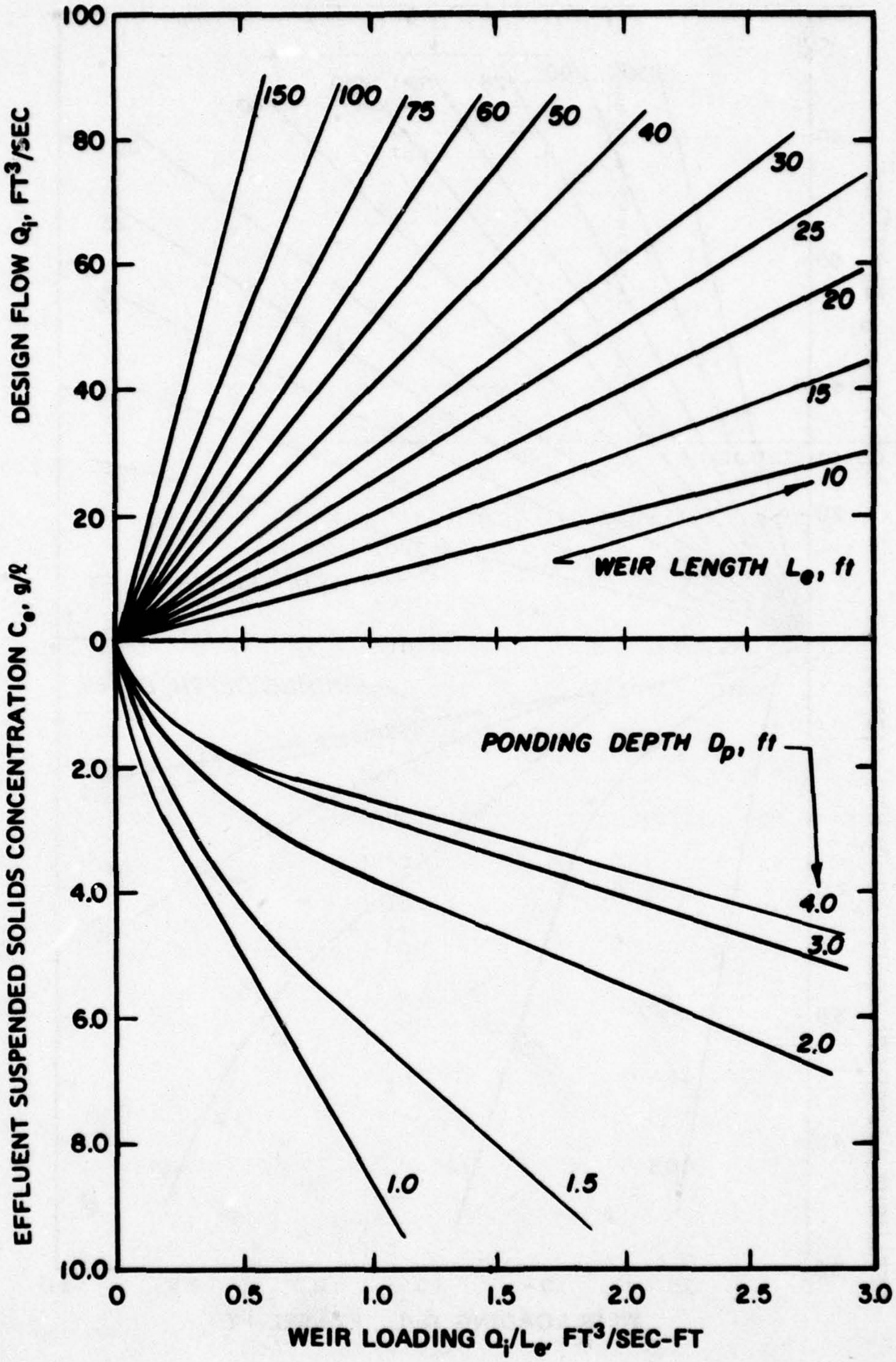

Figure 22. Weir design nomograph for freshwater clays (modified from Walski and Schroeder[19])

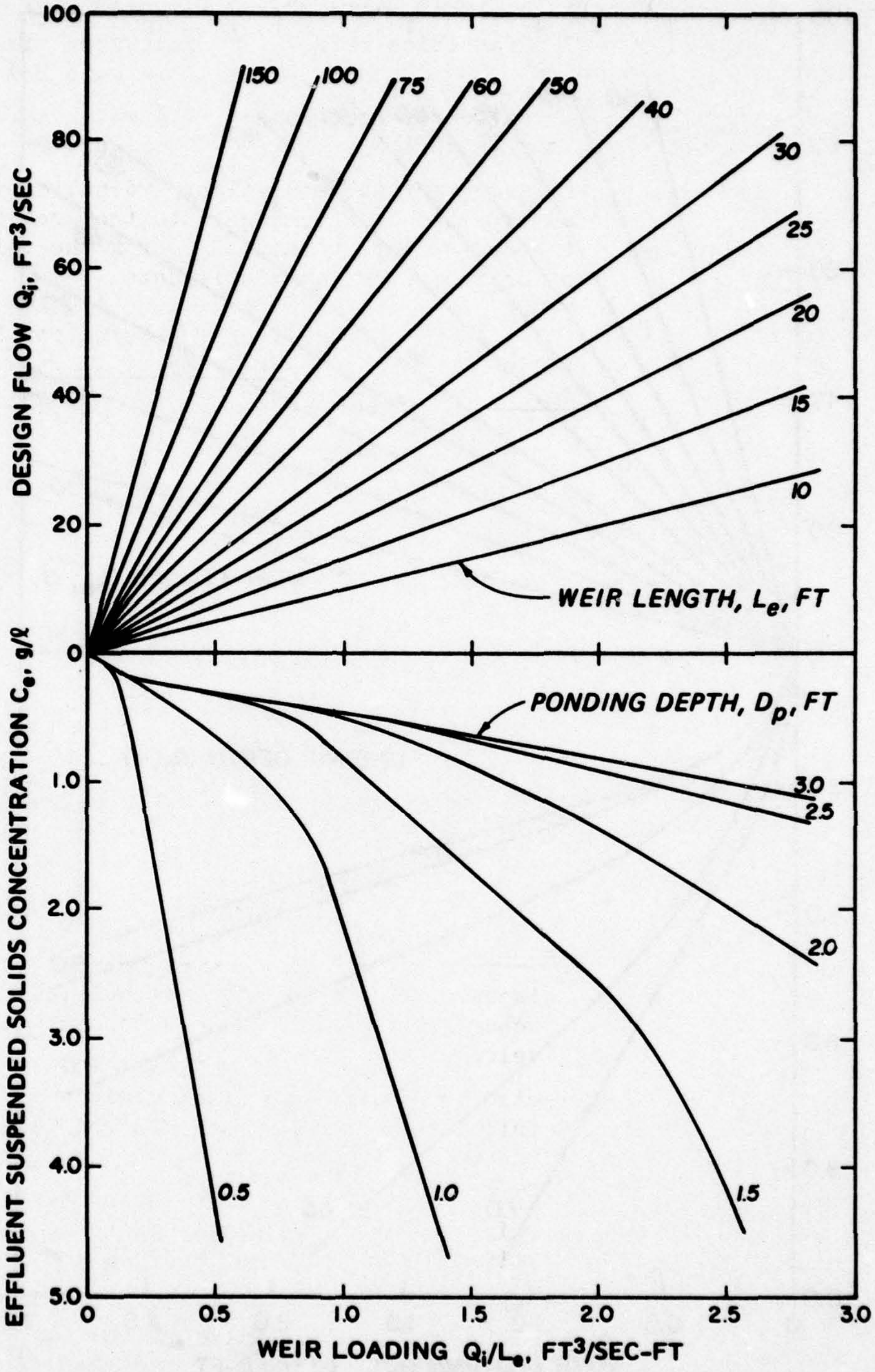

Figure 23. Weir design nomograph for all silts and saltwater clays (from Walski and Schroeder[19])

Salinity, ppt	Clay (CL, CH)	Silt (ML, MH)
1-3	Transition range	Saltwater nomograph (Figure 23)
>3	Saltwater nomograph (Figure 23)	Saltwater nomograph (Figure 23)

b. Determine the largest or the equivalent hydraulic pipeline dredge(s) expected to discharge into the area and then select the design inflow rate Q_i from the following tabulation or from other available data.

Discharge Pipeline Diameter, in.	Discharge Rate (for Flow Velocity of 15 ft/sec)* cfs	gal/min
8	5.3	2,350
10	8.1	3,640
12	11.8	5,260
14	16.0	7,160
16	20.6	9,230
18	26.5	11,860
20	32.7	14,660
24	47.1	21,090
27	59.5	26,630
28	64.1	28,700
30	73.6	32,950
36	106.0	47,500

* To obtain discharge rates for other velocities, multiply the discharge rate shown in this tabulation by the desired velocity and divide by 15.

c. Using the selected nomograph, construct horizontal lines at the design inflow rate Q_i and the desired level of effluent suspended solids.

d. Use vertical lines connecting the constructed horizontal lines to indicate various combinations of ponding depth and effective weir length required.

e. Determine the number of weir structures, physical dimensions of each, and locations based on the weir type to be used and the configuration of the containment area.

If a satisfactory balance between effective weir length and ponding depth cannot be achieved, intermittent operation will be required to meet the

desired level of effluent suspended solids as the containment area is filled. An illustrative problem is given in Appendix C.

Effect of weir type

113. Rectangular weirs. Rectangular weirs are the commonly used weir type and may consist of a rectangular wood- or metal-framed inlet or half-cylindrical corrugated metal pipe riser(s). The effective weir length is equal to the actual weir crest length for rectangular weirs as illustrated in Figure 24a.

114. Jutting weirs. A modified form of the rectangular weir is the jutting weir. It is possible to achieve a greater effective weir length using a jutting weir since the effective length L_e equals $L + 2J$, as shown in Figure 24b.

115. Polygonal (labyrinth) weirs. Polygonal (labyrinth) weirs have been used to reduce the depth of flow over the weir. However, use of such weirs has little impact on effluent suspended solids concentrations since the controlling factor for the depth of withdrawal is usually not the flow over the weir but the approach velocity. Therefore the approach velocity and the withdrawal depth for the rectangular weir in Figure 24a would be the same as that for the polygonal weir in Figure 24c since both weirs have the same effective length L_e even though the total weir crest length for the polygonal weir is considerably greater. Use of polygonal weirs is not recommended[8,19] because of the greater cost and the marginal improvement of effluent quality when using such a weir.

116. Shaft-type weirs. In some cases the outflow structure is a four-sided drop inlet or shaft located within the containment area as shown in Figure 24d. In evaluating the effective weir length for shaft-type weirs, the approach velocity is a key consideration. To minimize the approach velocity and hence the withdrawal depth, the shaft weir should not be placed too near the dike. In Figure 24d, location A is the most desirable since flow can approach from all sides (four effective sides). Location B is less desirable since flow can approach from only three directions (three effective sides). Location C is the least desirable since it has only two effective sides. Since effluent pipes

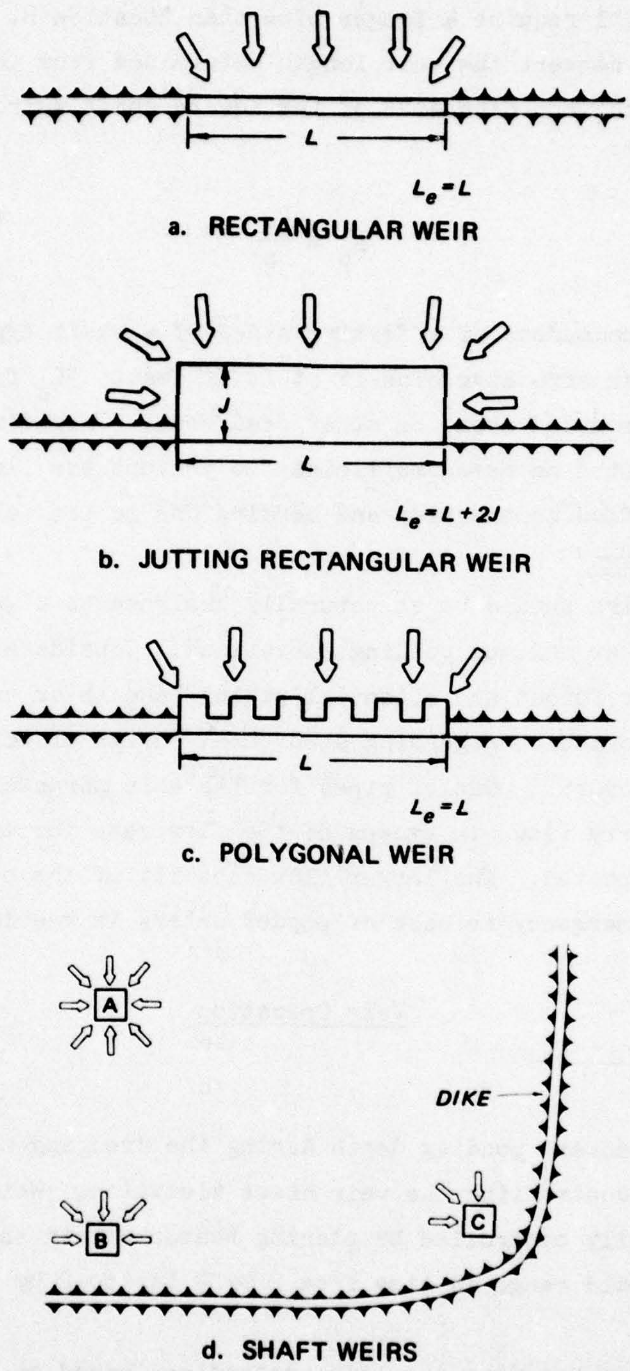

Figure 24. Effective lengths of various weir types (from Walski and Schroeder[19])

must run from the shaft weir under the dike to the receiving stream, a location such as A in Figure 24d may not be optimal since it is far from the dike and will require a longer pipe than Location B.

117. To convert the weir length determined from the design nomographs to length L_s of a side of the square shaft weir, use the following formula:

$$L_s = \frac{L_e}{n} \tag{21}$$

where n is the number of effective sides of a shaft type weir. A side is considered an effective side if it is at least $5L_s$ ft away from the nearest dike, mounded area, or other dead zone. This distance is generally accepted as being sufficient to prevent the flow restriction caused by the flow contraction and bending due to the walls.

Structural design

118. Weirs should be structurally designed to withstand anticipated loadings at maximum ponding elevations. Considerations should be given to uplift forces and potential piping beneath or around the weir. Additional information regarding structural design of weirs is found in another DMRP report.[2] Outlet pipes for the weir structure must be designed to carry flows in excess of the flow rate for the largest dredge size expected. The larger flow capacity of the outlet pipes may be needed if emergency release of ponded waters is required.

Weir Operation

Weir boarding

119. Adequate ponding depth during the dredging operation is maintained by controlling the weir crest elevation. Weir crest elevations are usually controlled by placing boards within the weir structure. The boards should range in size from 2 by 4 in. to 2 by 10 in. (nominal dimensions).

120. Weir boarding should be determined based on the maximum ponding elevation expected during the dredging operation. Before

dredging commences, the weir should be boarded to the highest possible elevation that dike stability considerations will allow. This practice will ensure maximum possible efficiency of the containment area. The maximum elevation must allow for adequate ponding depth above the highest expected level of accumulated settled solids and yet remain below the required freeboard. Small boards (e.g., 2 by 4 in.) should be placed at the top of the weir for a distance equal to the expected ponding depth at the end of the dredging operation. Use of larger boards in this most critical area may result in increased effluent suspended solids concentrations as weir boards are manipulated during the operation. Figure 25 shows the recommended weir boarding used for a ponding depth of 1 ft.

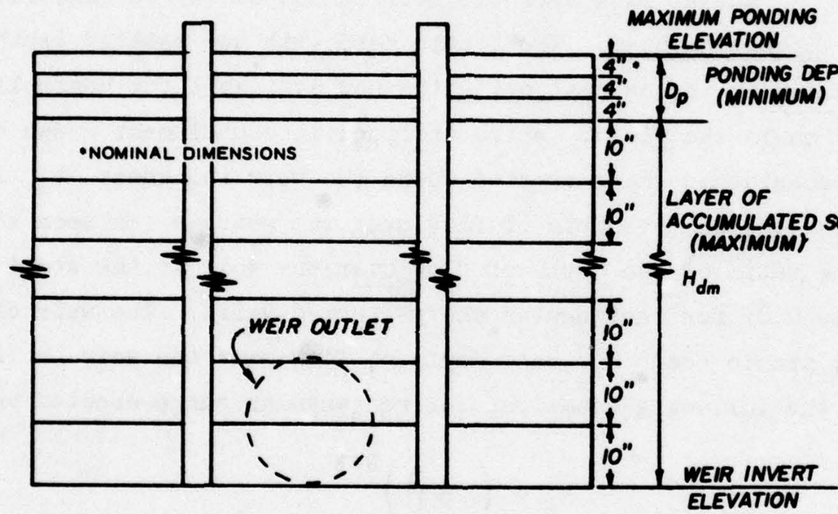

Figure 25. Recommended weir boarding configuration (modified from Walski and Schroeder[19])

Operational guidelines for weirs

121. General guidelines. Some basic guidelines for weir operation are given below.

a. If the weir is properly designed, intermittent operation should not become necessary until the required ponding depth cannot be maintained.

b. The weir crest should be maintained at the highest feasible elevation to ensure maximum effluent quality.

$\underline{c}$. While operating the weir, floating debris should be periodically removed from the front of the weir to prevent increased withdrawal flows from greater depths.

$\underline{d}$. If multiple weirs or a weir with several sections is used in a basin, the crests of all weirs or weir sections should be maintained at the same elevation.

$\underline{e}$. If the effluent suspended solids concentration rises above acceptable limits, the ponding depth should be increased by raising the elevation of the weir crest. However, if the weir crest is at the maximum ponding elevation and the effluent quality is still unacceptable, the flow into the basin must be decreased by operating intermittently.

$\underline{f}$. The weir may be controlled in the field by using the head over the weir as an operational parameter since the actual flow over the weir cannot easily be measured.

122. Operating head. The static head with the related depth of flow over the weir is the best criterion now available for controlling weir operation in the field. Weirs utilized in containment areas can usually be considered sharp crested where the weir thickness t_w is less than two thirds the depth of flow over the weir h as seen in Figure 21. The ratio of the depth of flow over the weir to the static head h/H_s equals 0.85 for rectangular sharp-crested weirs. The weir crest length L, static head H_s, and depth of flow over the weir h are related by the following equations for rectangular sharp-crested weirs:

$$H_s = \left(0.3\,\frac{Q}{L}\right)^{2/3} \tag{22}$$

and

$$h = 0.85H_s \tag{23}$$

where

Q = flow rate, ft^3/sec ($Q = Q_i = Q_e$ for continuous operation)

Q_e = clarified effluent rate, ft^3/sec

L = weir crest length, ft

These relationships are shown graphically in Figure 26.

123. For a desired flow rate and weir length, Figure 26 can be used to determine the maximum head allowable. If the head in the basin

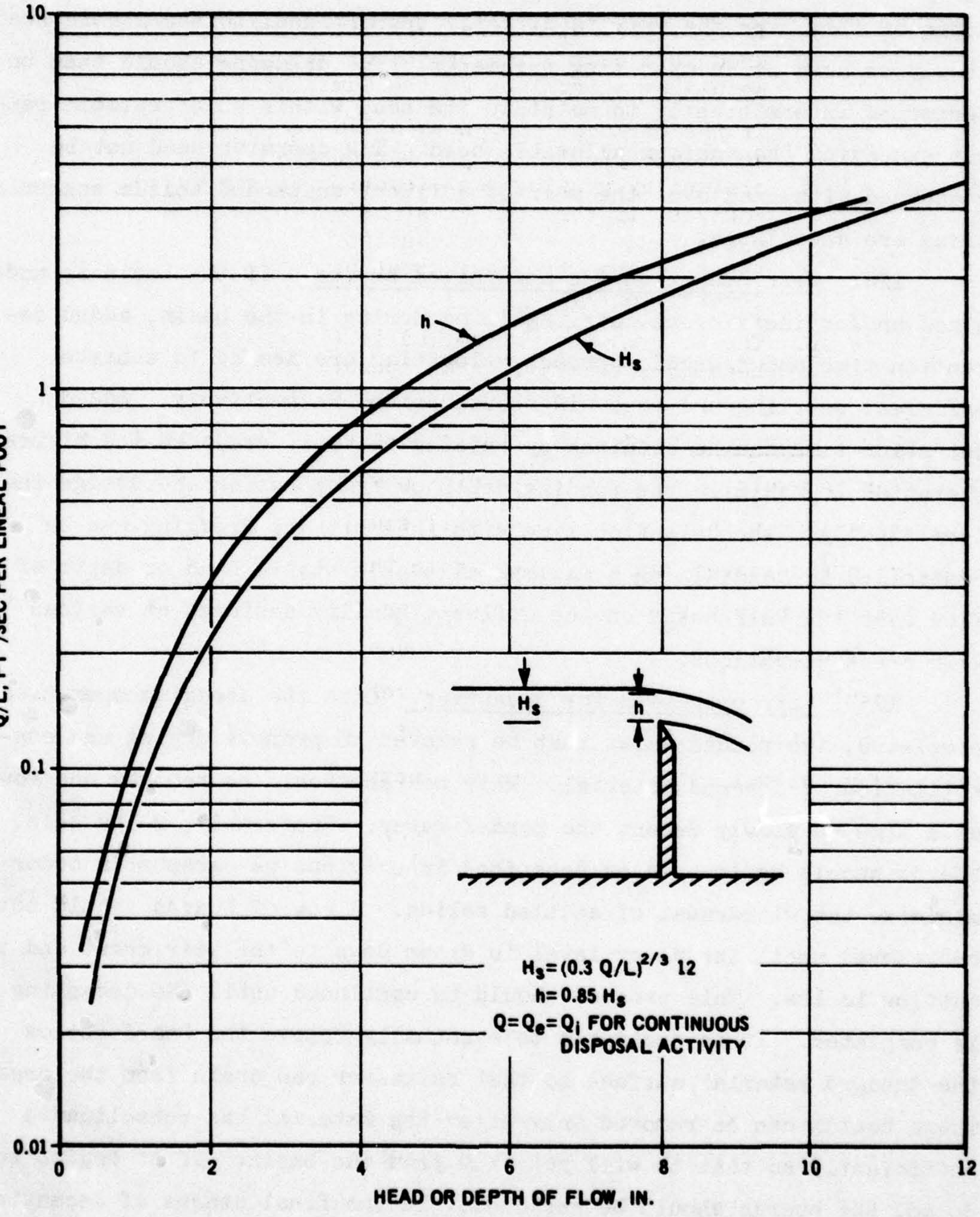

Figure 26. Relationship between flow rate, weir length, and head (modified from B. J. Gallagher and Co.[9])

exceeds this value, dredging should be discontinued until sufficient water is discharged to lower the head to an acceptable level. Since the depth of flow over the weir is directly proportional to the static head, it may be used as an operating parameter. The dredging should then be performed intermittently to maintain the head within an acceptable range, not exceeding the maximum allowable head. The operator need not be concerned with head over the weir if effluent suspended solids concentrations are acceptable.

124. Weir operation for undersized basins. If the basin is undersized and/or inefficient settling is occurring in the basin, added detention time and reduced approach velocities are needed to achieve efficient settling and to avoid resuspension, respectively. Added detention time can be obtained by raising the weir crest to its highest elevation to maximize the ponding depth or by operating the dredge intermittently. The detention time with intermittent dredging can be controlled by maintaining a maximum allowable static head or depth of flow over the weir based on the effluent quality achieved at various weir crest elevations.

125. Weir operation for decanting. Once the dredging operation is completed, the ponded water must be removed to promote drying and consolidation of dredged material. Weir boards should be removed one row at a time to slowly decant the ponded water. Preferably, 2- by 4-in. boards should be located as described in previous paragraphs in order to minimize the withdrawal of settled solids. A row of boards should not be removed until the water level is drawn down to the weir crest and the outflow is low. This process should be continued until the decanting is completed. It is desirable to eventually remove the boards below the dredged material surface so that rainwater can drain from the area. These boards can be removed only after the material has consolidated sufficiently so that it will not flow from the basin. If it begins to do so, the boards should be replaced. In the final stages of decanting ponded water, notched boards may be placed in the weir allowing low flow for slow removal of surface water.

PART VII: GUIDELINES FOR EFFECTIVE MANAGEMENT OF CONTAINMENT AREAS

126. This Part of the report presents procedures for effective management and operation of containment areas. Management activities performed before, during, and following the dredging operation are required to maximize retention of suspended solids and storage capacity of the containment area. The activities include site preparation, removal and use of existing dredged material for construction purposes, surface water management, suspended solids monitoring, inlet and weir management, thin-lift placement, separation of coarse material, dredged material dewatering, and disposal area reuse management. Management activities described in this Part are not applicable in all cases, but should be considered as possibilities for improving efficiency and prolonging the service life of containment areas.[24]

Predredging Management Activities

Site preparation

127. Immediately before a disposal operation, vegetation within the containment area should be investigated. Although vegetation may be beneficial because it helps dewater dredged material by transpiration and may improve the effluent quality by filtering, very dense vegetation may severely reduce the available storage capacity of the containment area and may restrict the flow of dredged slurry throughout the area causing short-circuiting. If removal of the vegetation is required, it should be delayed until immediately before the disposal operation to obtain the maximum amount of transpiration from previously placed material. Irregular topography within the containment area will directly affect resulting topography of the dredged material surface following the dredging operation. It may be beneficial to grade existing topography from planned inlet locations toward the weir locations to facilitate drainage of the area.

Use of existing dredged material

128. If dikes must be strengthened or raised to provide adequate

storage capacity for the next lift of dredged material, the use of the dried dredged material or suitable construction material from within the containment for this purpose will be beneficial. In addition to eliminating the costs associated with the acquisition of borrow, additional storage capacity is generated by removing material from within the area. Consideration should also be given to use of any coarse-grained material present from previous dredging operations for use in underdrainage blankets or for other planned applications requiring more select material.[3]

Containment Area Management During the Disposal Operation

Surface water management

129. The management of surface water during the disposal operation can be accomplished by controlling the elevation of the outlet weir(s) throughout the disposal operation to regulate the depth of water ponded within the containment area. Proper management of surface water is required to ensure containment area efficiency and can provide a means for access by boat or barge to the containment area interior.

130. At the beginning of the disposal operation, the outlet weir is set at a predetermined elevation which will ensure that the ponded water will be deep enough for settling as the containment area is being filled. As the disposal operation begins, slurry is pumped into the area; no effluent is released until the water level reaches the weir crest elevation. Effluent is then released from the area at about the same rate as slurry is pumped into the area. Thereafter, the ponding depth decreases as the thickness of the dredged material deposit increases. After completion of the disposal operation and the activities requiring ponded water, the water is removed as quickly as effluent water quality standards will allow. Figure 27 illustrates the concept.

131. Use of the ponded water for floating the pipeline within the containment area can be of benefit to general containment area mangement by greatly facilitating the movement of the inlet point without

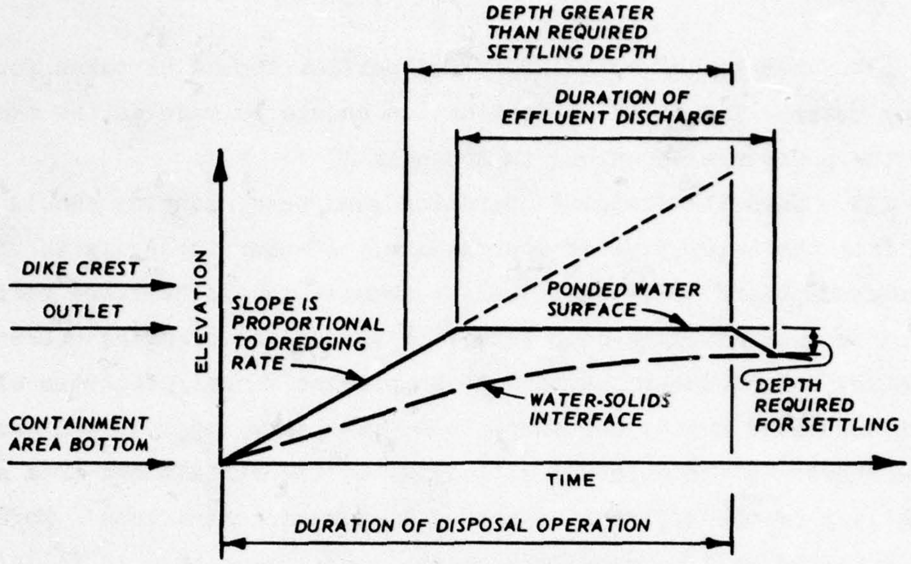

Figure 27. Surface water management (from Bartos[24])

disruption of the dredging operation. The floating inlet allows selective placement of coarse-grained material which will aid dewatering and drainage of fine-grained material.

132. Ponding of sufficient water permits access, by boat or small barge, to the interior of the containment area. This allows installation during the disposal operation of any necessary dewatering equipment or instrumentation requiring operation immediately after the surface water has been decanted. The depth required for this purpose is determined by the draft requirement of the vessel used.

Suspended solids monitoring

133. A well-planned monitoring program during the entire dredging and decanting operation is essential to ensure that effluent suspended solids remain within acceptable limits. Since suspended solids concentrations are determined on a grams per litre basis requiring laboratory tests, it is desirable to complete a series of laboratory tests during the initial stages of operation. Indirect indicators of suspended solids concentration such as visual comparison of effluent samples with samples of known concentration or utilization of a properly calibrated hydrometer may then be used during the remainder of the operation, supplemented with laboratory determination of effluent solids concentrations as needed for record purposes.

134. Samples of both inflow and outflow should be taken for laboratory tests. The solids determination should be made on the samples using the procedure described in Appendix A.

135. When the dredging operation commences, samples should be taken from the inlet pipe at approximately 12-hour intervals to verify design assumptions. Effluent quality samples should be taken periodically at approximately 6-hour intervals during the dredging operation for laboratory solids determinations to supplement visual estimates of effluent suspended solids concentrations. The sampling interval may be changed based on the observed efficiency of the containment area and the variability of the effluent suspended solids concentrations. More frequent sampling will be necessary as the containment area is filled and effluent concentrations increase.

Inlet and weir management

136. If multiple weirs are used, discharging the weirs alternately is sometimes useful for preventing short-circuiting. As the area between the inlet and one outlet fills, or as the inlet location is moved, the flow may channelize in a more or less direct route from inlet to weir. If this occurs, the flow should be diverted to another weir. Simultaneous discharge of slurry from several inlets located on the perimeter can also be advantageous, because the lower velocity of the slurry flow results in more pronounced mounding around the edge of the containment area. This mounding in turn increases the slope from inlet to outlet, and drainage will be improved.

137. The removal of water following the dredging operation can be somewhat expedited by managing inlets and weirs during the disposal operation to place a dredged material deposit that slopes continually and as steeply as practical toward the outlets. Figure 28 shows a containment area with a weir in one end and an inlet zone in the opposite end. Inlets are located at various points in the inlet zone, discharging either simultaneously (multiple inlets) or alternately (single movable inlet or multiple inlets discharging singly). A common practice is to use a single inlet, changing its location between disposal operations. The result of this practice is the buildup of several mounds, one near

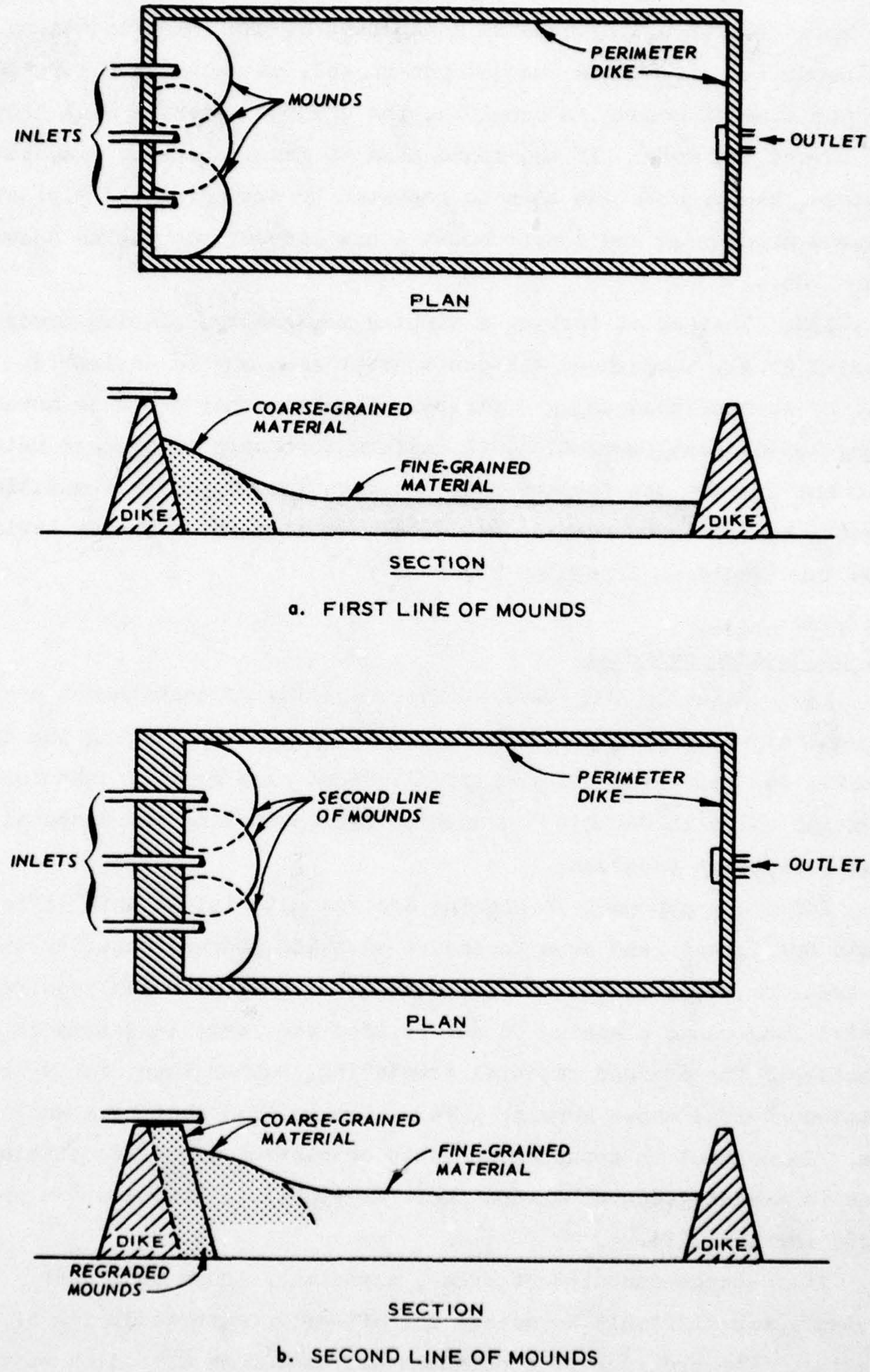

Figure 28. Inlet-weir management to provide smooth slope from inlet to weir (from Bartos[24])

each inlet location. By careful management of the inlet locations, a continuous line of mounds can be constructed, as shown in Figure 28a. When the line of mounds is complete, the dredged material will slope downward toward the weir. If the mound area is graded between disposal operations, the process can then be repeated by extending the pipe over the previous mound area and constructing a new line of mounds, as shown in Figure 28b.

138. Instead of forming a sloping topography, placing dredged material evenly throughout the containment area may be desirable. This could be accomplished using a floating pipeline that could be moved during the disposal operation. A uniform thickness of dredged material would not prevent the formation of a depression caused by foundation settlement, but the even surface would be less likely to develop isolated ponds than would an irregular surface.

Thin lift placement of dredged material

139. Gains in long-term storage capacity of containment areas through natural drying processes can be increased by placing the dredged material in thin lifts. Thin lift placement also greatly enhances potential gains in capacity through active dewatering and disposal area reuse management programs.

140. One approach to placing dredged material in thin lifts is to obtain sufficient land area to ensure adequate storage capacity without the need for thick lifts. Implementation of this approach requires careful long-range planning to ensure that the large land area is used effectively for dredged material dewatering, rather than simply being a containment area whose service life is longer than that of a smaller area. Government or sponsor ownership or control of large containment areas is advantageous to ensure their availability throughout a prolonged service life.

141. Large containment areas, especially those used nearly continuously are difficult to manage for effective natural drying of dredged material. The practice of continuous disposal does not allow sufficient time for natural drying. However, dividing of a large containment area

into several compartments can facilitate management because each compartment can be managed separately so that some compartments are being filled while the dredged material in others is being dewatered.

142. One possible management scheme for large compartmentalized containments is shown conceptually in Figure 29. For this operation thin lifts of dredged material are sequentially placed into each compartment. The functional sequence for each compartment consists of filling, settling and surface drainage, dewatering, and dike raising (using dewatered dredged material). The operation must be designed to

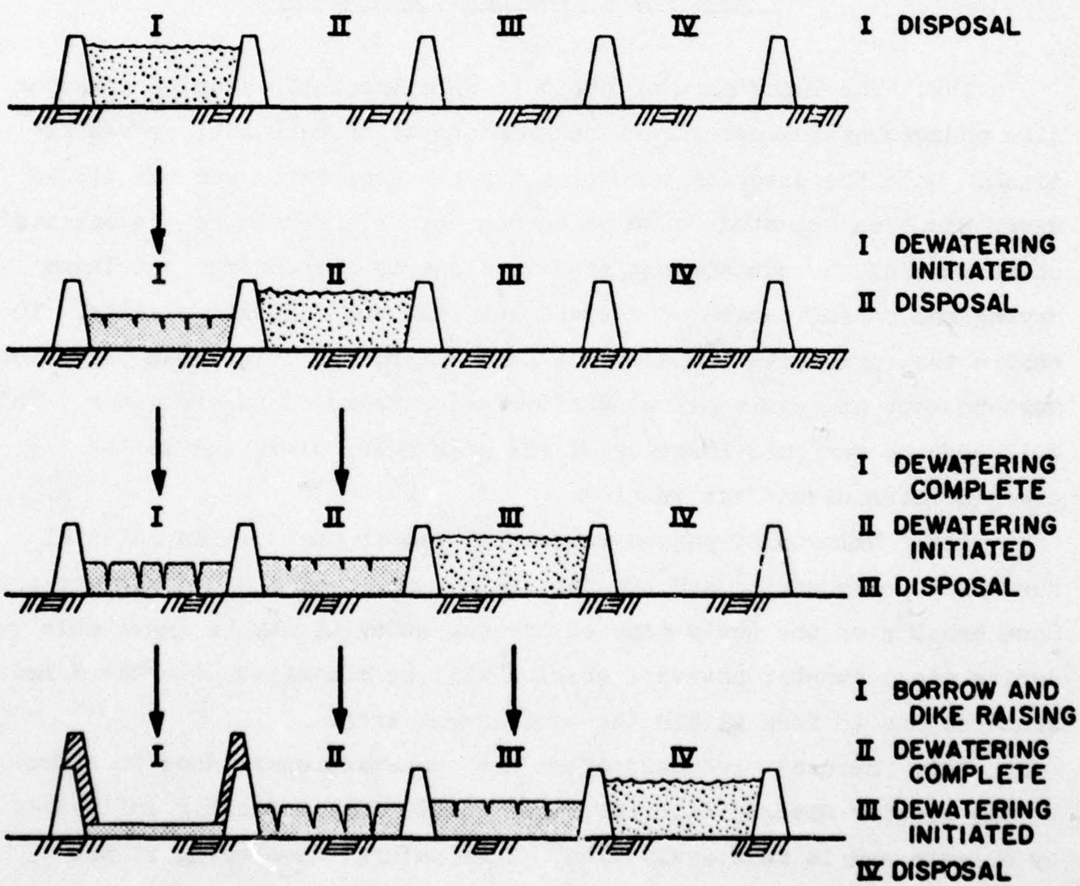

Figure 29. Conceptual illustration of sequential dewatering operations possible if disposal site is large enough to contain material from several periodic dredging operations (from Bartos[24])

include enough compartments to ensure that each thin lift is dried before the next lift is placed.

Separation of coarse material

143. The intentional separation of coarse material (sand and gravel) for later use and/or removal from the containment area may be accomplished through selective dredging and placement to enhance natural separation. Selective dredging involves placing sand and gravel into a selected area, while fine-grained and mixed coarse and fine dredged material is pumped to the containment area.[24]

Postdredging Management Activities

144. The importance of periodic site inspections and continuous site management following the dredging operation cannot be overemphasized. Once the dredging operation has been completed and the ponded water has been decanted, site management efforts should be concentrated on maximizing the containment storage capacity gained from continued drying and consolidation of dredged material and foundation soils. To ensure that precipitation does not pond water, the weir crest elevation must be kept at levels allowing efficient release of runoff water. This will require periodic lowering of the weir crest elevation as the dredged material surface settles.

145. Removal of ponded water will expose the dredged material surface to evaporation and promote the formation of a dried surface crust. Some erosion of the newly exposed dredged material may be inevitable during storm events; however, erosion will be minimized once the dried crust begins to form within the containment area.

146. Natural processes often need man-made assistance to effectively dewater dredged material since dewatering is greatly influenced by climate and is relatively slow. When natural dewatering is not acceptable for one reason or another, then additional dewatering techniques should be considered.

Implementation of Dredged Material Dewatering and Disposal Area Reuse Management (DARM)

Dredged material dewatering

147. Additional containment area storage capacity can be gained through active site management activities aimed at dewatering dredged material. The removal of excess water may add considerably to containment area storage volume, especially in the case of fine-grained dredged material. DMRP research in this area has identified promising techniques and has evaluated selected techniques in an extensive field study program.[25] The most successful dewatering techniques involve efforts to accelerate natural drying and desiccation of dredged material through increased surface drainage. Dewatering efforts may be implemented in conjunction with other periodic inspection and management activities of the containment area. Guidelines for estimating gains in capacity due to dewatering can be found in another DMRP synthesis report.[3]

DARM

148. Removal of coarse-grained material and dewatered fine-grained material through DARM techniques will further add to capacity and may be implemented in conjunction with dike maintenance or raising. In the case of fine-grained dredged material, DARM is a logical follow-up to successful dewatering management activities. This concept has been successfully used by Corps of Engineers Districts and demonstrated in field studies conducted by the DMRP.[26,27] Guidelines for determining potential benefits through DARM are found in another DMRP synthesis report.[4]

PART VIII: SUMMARY

149. In many cases, dredged material containment areas have been planned, designed, constructed, and operated on a level of effort far below that of other major projects. With an increased reliance placed on confined land disposal of dredged material, these projects now demand a level of effort in keeping with their importance and with the consequences of mismanagement.

150. This report has documented guidelines for designing, operating, and managing dredged material containment areas. Guidelines were concerned with all necessary field investigations and laboratory testing, sizing for retention of suspended solids and long-term storage capacity, weir design and operation, and containment area management before, during, and following the dredging operation. The guidelines provide Corps of Engineers Districts and Divisions with the necessary information for planning, designing, and operating dredged material containment areas in an efficient and cost-effective manner.

151. It is recommended that Districts and Divisions implement the guidelines contained in this report in planning, designing, and operating both existing and proposed containment areas. The implementation of the guidelines will allow verification and evaluation of improved performance and utilization of dredged material containment areas.

152. It is recommended that the performance of dredged material containment areas be monitored with regard to various design parameters, especially effluent quality and settlement. Monitoring of the containment areas will permit evaluation and verification of the prediction methodology by actual field performance.

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APPENDIX A: DETAILED TEST PROCEDURES

Organic Content Test

1. The following dry combustion test procedure is recommended to determine the organic content expressed as the percentage of weight lost on ignition:

   a. Dry a 40-g sample at 105°C until there is no further weight loss (usually 1 or 2 hours).

   b. Place it in a desiccator to cool for 15 min.

   c. Weigh the sample and place it in the oven at 440°C for 4 hours.

   d. Place it in the desiccator to cool for 15 min.

   e. Weigh the sample and determine the organic content by dividing the weight lost by the sample while in the oven at 440°C by the total weight of the sample at the time it was placed in the oven.

Flocculent Settling Test

2. Information required to design a containment area in which flocculent settling governs can be obtained using the following procedure:

   a. A settling column such as shown in Figure 3 of the main text is used. The test column depth should approximate the effective settling depth of the proposed containment area. A practical limit on depth of test is 6 ft. The column should be at least 8 in. in diameter with sample ports at 1-ft intervals. The column should have provisions to bubble air from the bottom to keep the slurry mixed during the column filling period.

   b. Mix the sediment slurry to the desired suspended solids concentration* in a container with sufficient volume to fill the test column. At least two tests should be performed at the concentration selected to represent the concentration of the dredged material influent C_i . Use the average detention time computed from these tests for design. Field studies indicate that for maintenance dredging in fine-grained material the disposal concentration will average about 145 g/ℓ.

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* Procedures for determining and reporting suspended solids concentrations are presented beginning in paragraph 10 of this Appendix.

c. Pump or pour the slurry into the test column using air to maintain a uniform concentration during the filling period.

d. When the slurry is completely mixed in the column, draw off samples at each sample port and determine their suspended solids concentration. Use the average of these values as the initial concentration at the start of the test. After the initial samples are taken, stop air bubbling and begin the test.

e. Allow the slurry to settle and withdraw samples from each sampling port at regular time intervals to determine the suspended solids concentrations. Sampling intervals depend on the settling rate of the solids (usually at 30-min intervals for the first 3 hours and then at 4-hour intervals until the end of the test). The sampling times can be adjusted after the first complete test. Continue the test until an interface of solids can be seen near the bottom of the column and the suspended solids concentration in the fluid above the interface is <1 g/ℓ. Test data are tabulated as shown in Table C1 of Appendix C.

f. If an interface has not formed within the first day on any previous tests, run one additional test with a suspended solids concentration sufficiently high to induce zone settling behavior. This test should be carried out according to the procedures outlined below for zone settling tests. The exact concentration at which zone settling behavior occurs depends upon the sediment being tested and cannot be predicted. The data from this test will be used to estimate the volume required for dredged material storage. The procedure for volume determinations is outlined in Part IV of the main text.

Zone Settling Test

3. Information required to design a containment area in which zone settling governs can be obtained by using the following procedure:

a. A settling column such as shown in Figure 3 of the main text is used. It is important that the column diameter be sufficient to reduce the "wall effect" and the test be performed with a test slurry depth near that expected in the field. Therefore, a 1-litre graduated cyclinder should never be used to perform a zone settling test for sediment slurries representing dredging disposal activities.

b. Mix the slurry to the desired concentration and pump or pour it into the test column. Test concentrations should

range from about 60 to 200 g/ℓ. Air may not be necessary to keep the slurry mixed if the filling time is less than 1 min.

c. Record the depth to the solid-liquid interface with respect to time. Readings must be taken at regular intervals to gain data for plotting the depth to interface versus time curve shown in Figure A1. It is important to take enough readings to clearly define this curve for each test.

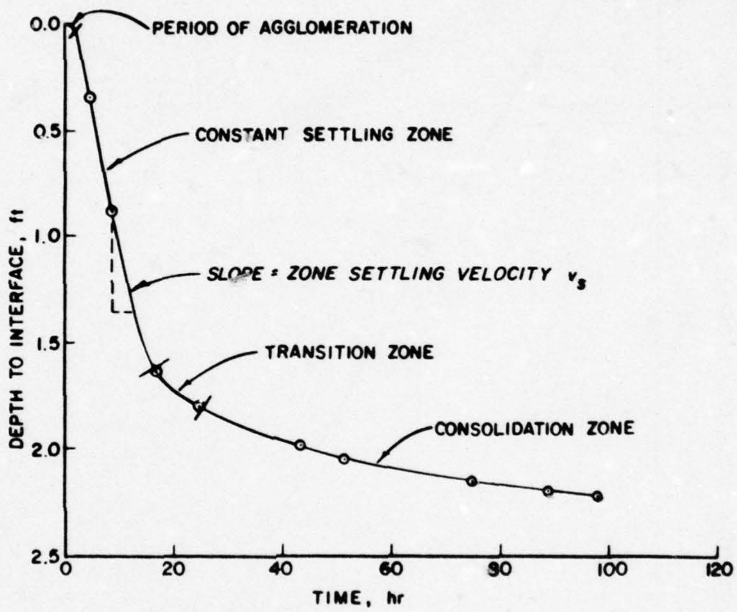

Figure A1. Typical settling curve for dredged material (from Montgomery[8])

d. Continue the readings until sufficient data are available to define the maximum point of curvature of the depth to interface versus time plot (Figure A1) for each test. Tests may require from 1 to 5 days to complete.

e. Perform a minimum of eight tests. Data from these tests are required to develop the zone settling velocity versus concentration curve shown in Figure A2.

f. One of the above tests should be performed on sediment slurries at a concentration of about 145 g/ℓ. This test should be continued for a period of at least 15 days to provide data for estimating volume requirements.

AD-A073 138 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/G 13/3
GUIDELINES FOR DESIGNING, OPERATING, AND MANAGING DREDGED MATER--ETC(U)
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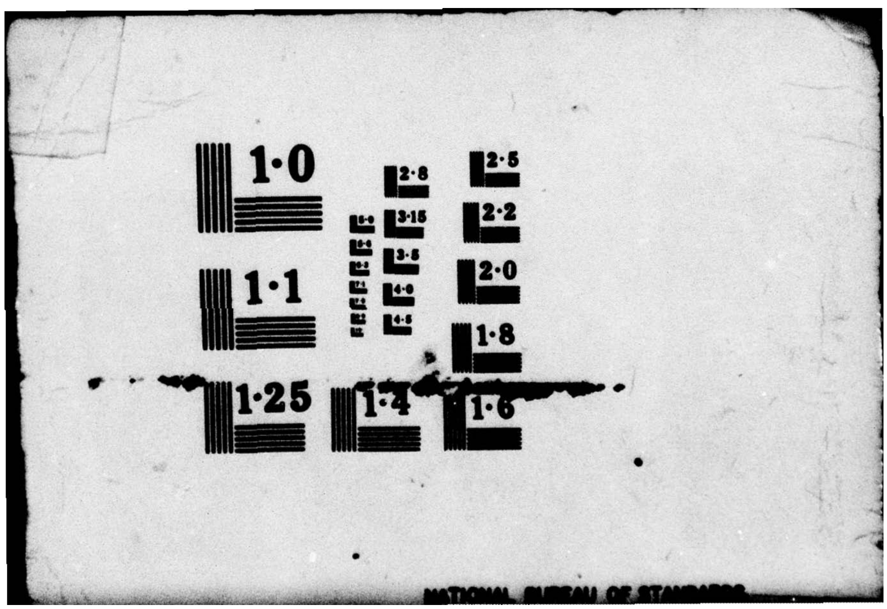
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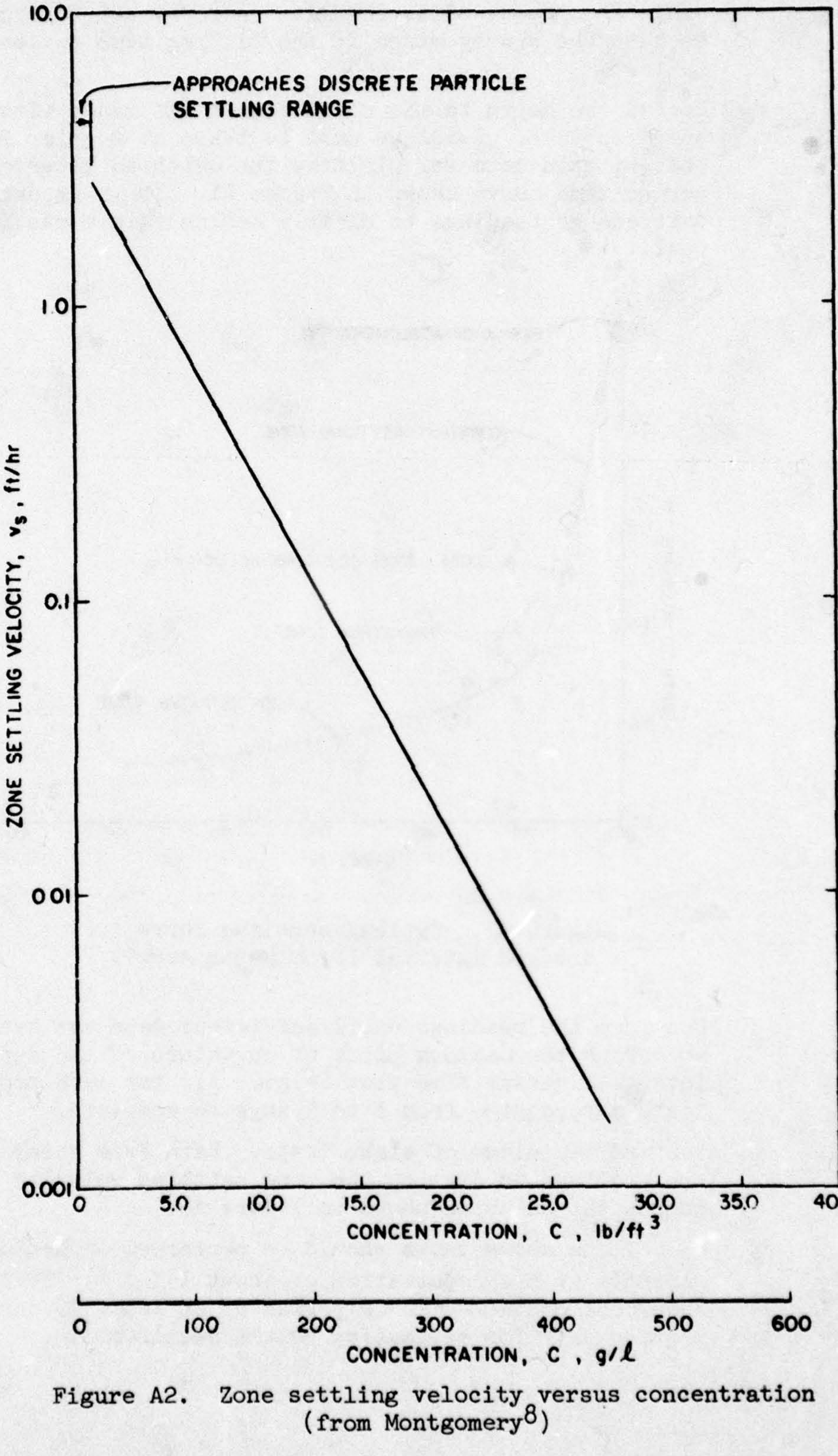

Figure A2. Zone settling velocity versus concentration (from Montgomery[8])

Consolidation Test

Sample preparation

4. Samples of sediment used for the consolidation test must be representative of the fine-grained portion of the material to be dredged. In the case of a relatively homogeneous fine-grained sediment, consolidation samples can be taken directly from sediment samples obtained during the field investigation phase. For sediments that contain mixtures of sand (>10 percent dry weight), a more representative consolidation sample can be obtained if the sand fraction has previously been separated. For this case, the consolidation test should be performed on a sample with initial water content/void ratio approximately equal to that at the end of the dredging operation, determined by the sizing procedures given in Part IV.

5. Since sediment samples are essentially without structure, consolidation samples can be placed in the consolidation ring in a remolded condition. The ring should be placed on a flat plate prior to filling. The remolded sample should not be allowed to drain while being placed in the ring; care should also be taken to ensure that no air pockets have formed within the sample or along the ring wall. A sufficient quantity of material representative of that used for the consolidation sample must also be preserved for specific gravity and water content determinations.

Loading procedure

6. The initial load should not exceed 0.005 tsf. The relatively low initial load is necessary to adequately define behavior at low effective stresses. The seating load plus the compression load caused by the dial indicator should be considered as the initial loading increment for the test. Dial indicators used should provide a travel distance capable of continuous measurement of the larger strains expected for a highly compressible material. The dial indicator force can be estimated using a balance reading, in grams, obtained with the indicator compressed to approximately that setting to be used when the test is initiated.

7. The seating load consisting of the porous stone, loading plate,

and ball bearings should be applied very carefully. While the dial indicator stem is manually held to prevent additional loading of the sample, the dial indicator should be positioned. The stem should then be lowered until it just makes contact; an initial dial reading should be taken. The dial indicator stem should then be released to apply the remainder of the initial load increment.

8. Succeeding load increments may be placed using the normal beam and weight or pneumatic loading devices. The following loading schedule is recommended: 0.005, 0.01, 0.02, 0.05, 0.10, 0.25, 0.50, and 1.0 tsf. A maximum loading of 1.0 tsf should be adequate for most applications. However, the effective stress acting at the bottom of the dredged material layer at the end of the containment area service life should be estimated to determine if higher maximum load increments are necessary.

9. Time-consolidation data should be examined while the test is in progress to ensure that 100 percent primary consolidation is reached for each load increment. In some cases, it may be necessary to allow 48 hours for each increment. Rebound loadings are not required.

Suspended Solids Test

10. If suspended solids determinations are to be made on slurries obtained from a saltwater environment (>3 ppt), either the centrifugation or the filtration method should be used. The total solids method should be used for slurries obtained from a freshwater environment.

Centrifugation method

11. This method is best for slurries that will not readily filter.

- a. Pour 20 ml of slurry into two centrifuge tubes.
- b. Spin for about 3 min (depending on the speed generated). The time and speed should be sufficient to pack the solids and produce a clear liquid.
- c. Pour off the liquid. If the solids are disturbed, repeat the procedure using a new sample and a longer spin time.
- d. Resuspend the solids with distilled water. Fill to 20 ml with distilled water.
- e. Repeat step b.

f. Resuspend the solids with distilled water. Wash all solids into a preweighed aluminum dish.

g. Put the dish in the oven at 105°C. Leave the specimen in the oven until it has dried to a constant weight (usually 4 to 6 hours).

h. Place the dish in the desiccator to cool for 15 min.

i. Weigh and calculate the concentration of suspended solids in grams per litre as:

$$C = [(\text{weight of dish and dry solids, g}) - (\text{weight of dish, g})] \div 0.02$$

Filtration method

12. This method is recommended when the solids permit easy filtering.

a. Weigh a Gooch crucible and filter paper.

b. Put about 10 ml of slurry into the crucible and impose a vacuum.

c. Wash with 10 ml of distilled water to eliminate dissolved solids.

d. Remove the crucible and place it in the oven at 105°C until it has dried to a constant weight (usually 4 to 6 hours).

e. Cool in the desiccator for 15 min and weigh.

f. Calculate the concentration of suspended solids in grams per litre as:

$$C = [(\text{weight of crucible, filter paper, and dry solids, g}) - (\text{weight of crucible and filter paper, g})] \div 0.01$$

Total solids method

13. If the sediment or dredged material is obtained from a fresh-water environment, the dissolved solids are not likely to be significant. In this case determination of the concentration of total solids will be sufficient.

a. Determine the dish weight.

b. Put the sample into the dish and weigh.

c. Place in the oven at 105°C until the sample has dried to a constant weight. Cool in the desiccator for 15 min and weigh.

d. Calculate the solids concentration in percent solids by weight as follows:

$$\%S = [(\text{weight of dry specimen and dish} - \text{dish weight}) \div (\text{weight of wet specimen and dish} - \text{dish weight})] \times 100$$

e. Use Figure 4 in the main text to convert concentration in percent solids by weight to concentration in grams per litre.

APPENDIX B: SUMMARY OF DESIGN DATA REQUIREMENTS

1. The purpose of this Appendix is to assist the designer in obtaining samples and performing laboratory tests required to apply the design techniques presented in this report. This Appendix is a guide only and should be used to supplement the other information contained within the report. Table B1 presents a listing of the samples which must be obtained from the field and also identifies areas in which special care should be taken and consideration given in handling the samples. In Table B2 the tests to be performed on the samples are identified; tests requiring other than standard procedures are noted here. Table B3 gives an overview of all items required to complete the containment area design.

Table B1

Sampling Requirements

Sample Type	Reference by Main Text Paragraph No. — General	Quantity	Preservation
Water	11		
Sediment	9, 10, 12-18	14-16	17-18
Foundation material	19-23	*	*

* See other publications noted in the main text.

Table B2

Testing Requirements

Sample Type	Required Test	Symbol	Remarks
Water	Salinity		Standard test
Sediment	Natural water content	w	Standard test
	Grain size analysis		Use material retained on No. 40 sieve
	Plasticity (Atterberg limits)		Use material passing No. 40 sieve
	Liquid limit	LL	
	Plastic limit	PL	
	Plasticity index	PI	
	Organic content	OC	Recommended procedure in Appendix A
	Specific gravity	G_s	Standard test
	USCS classification		Material separated on No. 40 sieve
	Sedimentation		Special test procedure in Appendix A
	Consolidation		Special test procedure in in Appendix A
Foundation material*	Natural water content	w	Standard test
	Grain size analysis		Standard test
	Plasticity (Atterberg limits)		Standard tests
	Liquid limit	LL	
	Plastic limit	PL	
	Plasticity index	PI	
	Organic content	OC	Recommended procedure in Appendix A
	Specific gravity	G_s	Standard test
	USCS classification		Standard test
	Consolidation		Standard test

* Tests run on each compressible foundation material are intended only for sample classification which will aid in selection of consolidation samples.

Table B3

Data Requirements

Major Element	Data Item	Symbol	How Obtained	Reference by Main Text Paragraph No.
Project information	Anticipated dredge size		Past experience	54
	Average distance to containment area		Analysis of work site	54
	Average depth of dredging		Analysis of work site	54
	Inflow rate	Q_i	Past experience or Figure 6 in main text	54,55
	Inflow solids concentration	C_i	Past experience or 145 g/ℓ (13% by weight)	55
	In situ volume to be dredged	V_i	Hydrographic surveys	52
	Allowable effluent solids concentration	C_e	Legal constraints	
Sediment properties	Salinity		Lab test of water sample	27
	In situ water content	w	Lab test	28
	Grain size analysis		Lab test	29-31
	Plasticity (Atterberg limits)		Lab tests	32
	Liquid limit	LL		
	Plastic limit	PL		
	Plasticity index	PI		
	Organic content	OC	Lab test	33
	Specific gravity of solids	G_s	Lab test	34
	USCS classification		Analysis of grain size and plasticity tests	35
	In situ void ratio	e_i	Equation using w and G_s	53
	Degree of saturation	S_D	Normally 100% for sediments	53

(Continued)

(Sheet 1 of 3)

Table B3 (Continued)

Major Element	Data Item	Symbol	How Obtained	Reference by Main Text Paragraph No.
Foundation material properties	In situ water content	w	Lab test	28
	Grain size analysis		Lab test	31
	Plasticity (Atterberg limits)		Lab tests	32
	Liquid limit	LL		
	Plastic limit	PL		
	Plasticity index	PI		
	Organic content	OC	Lab test	33
	Specific gravity of solids	G_s	Lab test	34
	USCS classification		Analysis of grain size and plasticity tests	35
	In situ void ratio	e_1	Equation using w and G_s	91*
Sedimentation properties (salt water)	Zone settling velocity	v_s	Lab test	43,58
	Solids loading	S	Lab test	58
	Design solids concentration	C_d	Lab test	59
	Design solids loading	S_d	Lab test	60
	Surface area required for sedimentation	A_d	Lab test	60
Sedimentation properties (fresh water)	Solids removal percentages	R	Lab test	63
	Detention time	T	Lab test	63
	Design solids concentration	C_d	Lab test	63
	Volume required for sedimentation	V_B	Lab test	68

(Continued)

* Procedure given in Reference 20 which is cited in main text.

(Sheet 2 of 3)

Table B3 (Concluded)

Major Element	Data Item	Symbol	How Obtained	Reference by Main Text Paragraph No.
Consolidation properties (dredged material and foundation material)	Coefficient of consolidation	c_v	Lab test	96*
	Coefficient of permeability**	k	Lab test	91*
	Void ratio-pressure relationship	e-log p	Lab test	91*
	Coefficient of volume change**	m_v	Lab test	91*
	Average void ratio at completion of primary consolidation	e_f, e_2	Lab test	90,95
	Average length of drainage path	H_d	Analysis of field investigations and permeability test results	96*
Containment area data	Thickness of compressible foundation material(s)		Soil borings	19
	Dike height (if existing)	D	Analysis of work site	67-69
	Ponding depth	H_{pd}	Design parameter	7,67,72,112
	Freeboard	H_{fb}	Design parameter	7,67
	Effective weir length	L_e	Design parameter (new weir) or analysis of work site (existing weir)	112
	Void ratio of dredged material at completion of dredging	e_o	Lab test	65
	Change in volume of fine-grained sediment	ΔV	Analysis of hydrographic surveys and sedimentation test results	65
	Volume of coarse-grained sediment	V_{sd}	Lab test	65
	Total volume required for storage at completion of dredging	V	Analysis of field investigations and lab tests	65

* Procedure given in Reference 20 which is cited in main text.
** Needed for mathematical model.

(Sheet 3 of 3)

APPENDIX C: EXAMPLE DESIGN CALCULATIONS

1. This Appendix presents example calculations for containment area designs. The examples are developed to illustrate use of field and laboratory data and include designs for sedimentation, weir design, and requirements for storage capacity. Separate examples are developed for saltwater and freshwater sedimentation designs as described in Part IV of the main text. Examples illustrating settlement computations and use of mathematical models for estimating settlement as described in Part V of the main text are also given. Only those calculations necessary to illustrate the procedure are included in the examples.

Example I: Containment Area Design Method for Freshwater Sediments

Project information

2. Each year an average of 300,000 yd^3 of fine-grained channel sediment is dredged from a harbor on Lake Michigan. A new in-water containment area is being constructed to accommodate the long-term dredged material disposal needs in this harbor. However, the new containment area will not be ready for approximately 2 years. One containment area in the harbor has some remaining storage capacity but it is not known whether the remaining capacity is sufficient to accommodate the immediate disposal requirements. Design procedures must be followed to determine the detention time needed to meet effluent requirements of 4 g/ℓ and the storage volume required for the 300,000 yd^3 of channel sediment. These data will be used to determine if the existing containment area storage capacity is sufficient for the planned dredged material disposal activity. The existing containment area is about 3 miles from the dredging activity.

3. Records indicate that for the last three dredgings, an 18-in. pipeline dredge was contracted to do the work. The average working time was 17 hours per day, and the dredging rate was 600 yd^3 per hour of in situ channel sediment. The project depth in the harbor is 50 ft.

Results of containment area survey

4. The existing containment area has the following dimensions:

<u>a</u>. Size: 96 acres.

<u>b</u>. Shape: length-to-width ratio of about 3.

<u>c</u>. Volume: 1,548,800 yd^3 (average depth, from surveys, is 10 ft).

<u>d</u>. Weir length: 24 ft (rectangular weir).

Results of laboratory tests and analysis of data

5. The following data were obtained from laboratory tests as described in the main text:

<u>a</u>. Salinity: <1 ppt.

<u>b</u>. Channel sediment in situ water content w : 85 percent.

<u>c</u>. Specific gravity G_s : 2.69.

<u>d</u>. Observed flocculent settling concentrations as a function of depth (see Table C1).

<u>e</u>. Percent of initial concentration with time (see Table C2).

This is determined as follows:

Column concentration at beginning of tests is 132 g/ℓ. Concentration at 1-ft level at time = 30 min is 46 g/ℓ (Table C1). Percent of initial concentration = 46 ÷ 132 = 0.35 = 35 percent. These calculations are repeated for each time and depth to develop Table C2.

<u>f</u>. Plot the percent of initial concentration versus depth profile for each time interval from data given in Table C2 (see Figure C1).

<u>g</u>. Determine concentration as a function of time (15-day settling column data) (see Table C3).

<u>h</u>. Plot time versus concentration from data in Table C3 as shown in Figure C2.

<u>i</u>. Laboratory tests indicate that 20 percent of the sediment is coarse-grained material (>No. 40 sieve); therefore, the volume of coarse-grained material V_{sd} is

$$V_{sd} = 300{,}000(0.20) = 60{,}000 \ yd^3$$

and the volume of fine-grained material V_i is:

Table C1

Observed Flocculent Settling Concentrations with Depth, in Grams per Litre (from Montgomery[8*])

Time, min	Depth from Top of Settling Column, ft 1	2	3	4	5	6	7
0	132	132	132	132	132	132	132
30	46	99	115	125	128	135	146
60	25	49	72	96	115	128	186
120	14	20	22	55	78	122	227
180	11	14	16	29	75	119	
240	6.8	10.2	12	18	65	117	
360	3.6	5.8	7.5	10	37	115	
600	2.8	2.9	3.9	4.4	14	114	
720	1.01	1.6	1.9	3.1	4.5	110	
1020	0.90	1.4	1.7	2.4	3.2	106	
1260	0.83	1.14	1.2	1.4	1.7	105	
1500	0.74	0.96	0.99	1.1	1.2	92	
1740	0.63	0.73	0.81	0.85	0.94	90	

Note: Data from actual test on freshwater sediments. Although a 6-ft test depth is recommended, an 8-ft depth was used in this test.

* Raised numbers refer to similarly numbered items in the References at the end of the main text.

Table C2

Percent of Initial Concentration with Time

(from Montgomery[8])

Time T, min	Depth from Top of Settling Column, ft 1	2	3
0	100	100	100
30	35	75	87
60	19	37	55
120	11	15	17
180	8	11	12
240	5	8	9
360	3	4	6
600	2.0	2.2	3.0
720	1.0	1.2	1.4

Note: Initial suspended solids concentration = 132 g/ℓ.

Table C3

Concentration as a Function of Time

(from Montgomery[8])

Time days	Concentration g/ℓ
1	190
2	217
3	230
4	237
5	240
6	242
7	244
9	249
10	247
15	256

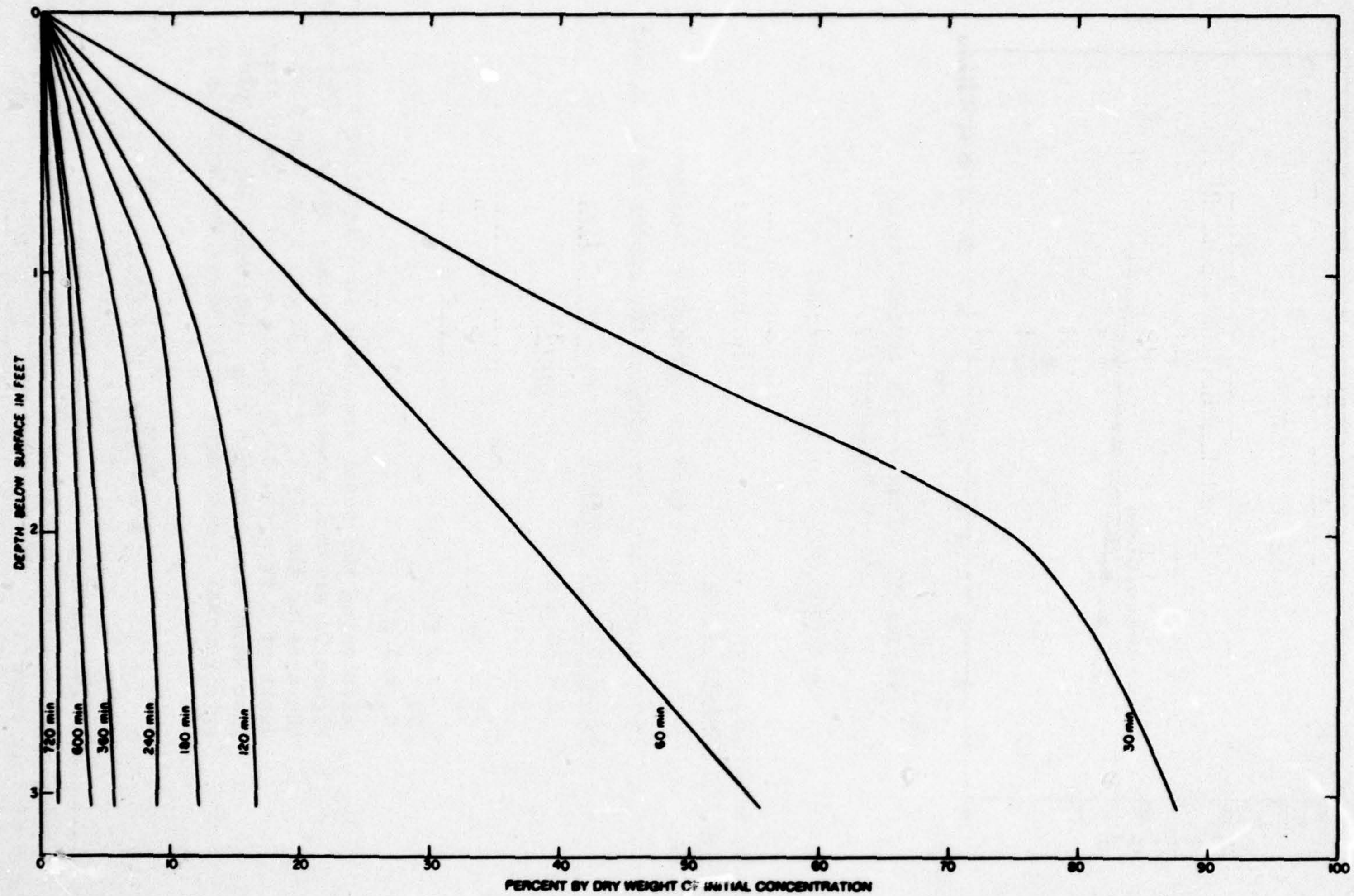

Figure C1. Percent of initial concentration versus depth profile (from Montgomery[8])

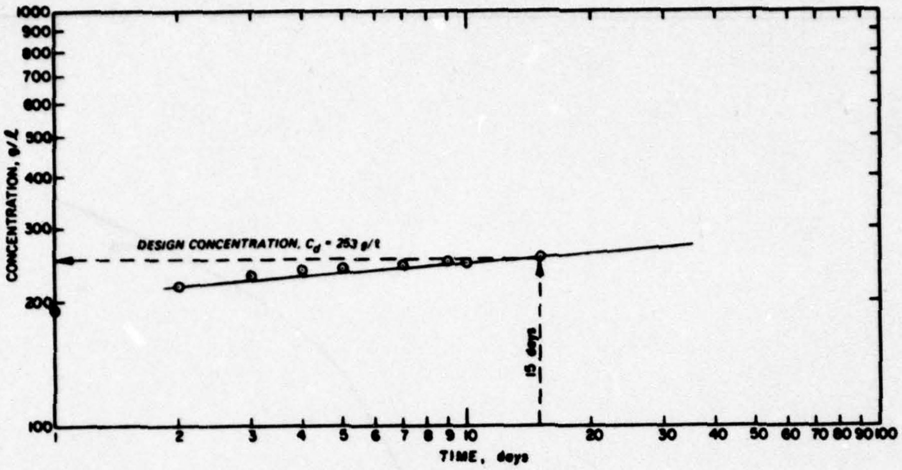

Figure C2. Time versus concentration (from Montgomery[8])

$$V_i = 300{,}000 - 60{,}000 = 240{,}000 \text{ yd}^3$$

Compute detention time
required for sedimentation

6. The design detention time is computed as follows:

   a. Calculate removal percentages for depths of 1, 2, and 3 ft.

   Example calculations:

   $t = 30$ min

   $d = 1$ ft

   $C_i = 132$ g/l

   $H_{pd} = 2$ ft

   $C_e = 4$ g/l

   Calculating the total area down to a depth of 1 ft from Figure C1 gives an area of 100 (scale units). Calculating the area to the right of the 30-min time line down to a depth of 1 ft gives 82.5 (scale units). These areas could also have been determined by planimetering the plot. Compute removal percentages as follows (see Equation 5*):

$$R = \frac{82.5}{100} \times 100 = 82.5$$

---

* Equation numbers refer to similarly numbered equations in the main text of this report.

For a settling time of 30 min, 82.5 percent of the suspended solids are removed from the water column above the 1-ft depth.

b. The calculations illustrated in step a are repeated for each depth as a function of time and the results are tabulated in Table C4.

Table C4

Removal Percentages as a Function of Settling Time (from Montgomery[8])

Time, min	Depth from Top of Settling Column, ft 1	2	3
30	82.5	62.0	47.0
60	91.0	81.0	73.0
120	93.7	90.2	88.1
180	95.8	93.1	91.5
240	97.4	95.5	94.2
360	98.0	97.0	96.2
600	98.9	98.4	98.1
720	99.6	99.3	99.1

c. Plot the data in Table C4 as shown in Figure C3.

d. Since the average ponding depth H_{pd} is 2 ft, use the 2-ft depth curve shown in Figure C3 and determine the theoretical detention time required to meet the 4-g/ℓ effluent suspended solids requirement.

$$\text{Required Solids Removal} = \frac{C_i - C_e}{C_i}$$

$$= \frac{132 - 4}{132} = 0.97 \text{ or } 97 \text{ percent}$$

e. From Figure C3, T = 365 min.

f. Increase the theoretical detention time T by a factor of 2.25:

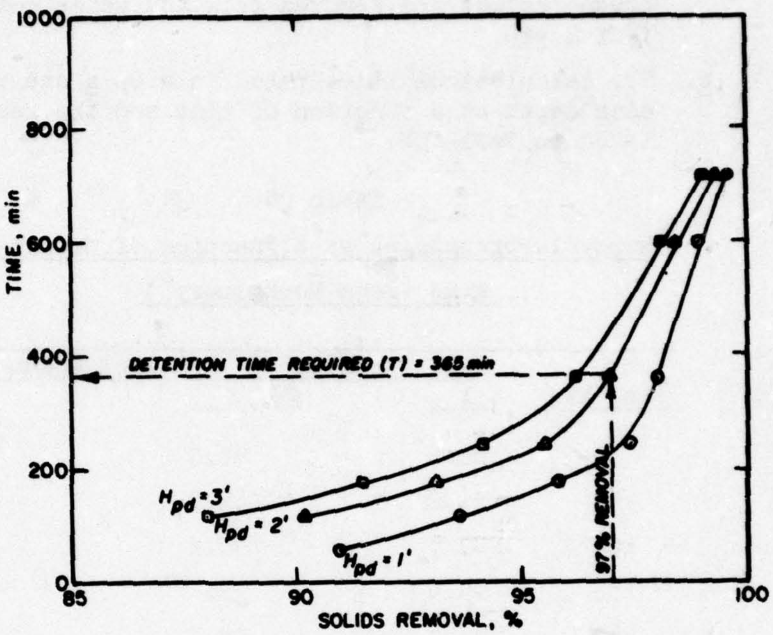

Figure C3. Solids removal versus time as a function of depth (from Montgomery[8])

$$T_D = 2.25T$$

$$T_D = 2.25(365)$$

The design detention time T_d equals 822 min.

<u>Compute volume required for sedimentation</u>

7. Compute this value as follows:

$$V_B = Q_i T_d$$

$$Q_i = \frac{\frac{18 \text{ in.}^2}{12}\,\pi}{4} \times 15 \text{ ft/sec}$$

$$= 26.5 \text{ ft}^3/\text{sec}$$

$$= 1590.4 \text{ ft}^3/\text{min}$$

$$V_B = 1,590.4(822) \approx 1,300,000 \text{ ft}^3$$

Compute de-
sign concentration

8. Compute this value as follows:

a. Project information:

(1) Dredge size: 18 in.

(2) Volume to be dredged: 300,000 yd^3.

(3) Average operating time: 17 hours per day.

(4) Production: 600 yd^3 per hour.

b. Estimate time of dredging activity:

$$\frac{300{,}000\ yd^3}{600\ yd^3/hour} = 500\ hours$$

$$\frac{500\ hours}{17\ hours/day} = 29.4 \approx 30\ days$$

c. Average time for dredged material consolidation:

$$\frac{30\ days}{2} = 15\ days$$

d. Design solids concentration C_d is the concentration shown in Figure C2 at 15 days:

$$C_d = 253\ g/\ell$$

Estimate volume re-
quired for dredged material

9. Estimate this volume as follows:

a. Compute average void ratio e_o using Equation 7:

$$e_o = \frac{G_s \gamma_w}{\gamma_d} - 1$$

$$G_s = 2.69$$

$$\gamma_w \approx 1000\ g/\ell$$

$$\gamma_d = 253\ g/\ell$$

$$e_o = \frac{2.69(1000)}{253} - 1$$

$$e_o = 9.63$$

b. Compute change in volume of fine-grained channel sediments after disposal in containment area using Equation 8:

$$\Delta V = V_i \frac{e_o - e_i}{1 + e_i}$$

$$e_i = \frac{wG_s}{S_D} \qquad \text{(Equation 2)}$$

$$= \frac{(85/100)(2.69)}{1.00}$$

$$e_i = 2.29$$

$$V_i = 240{,}000 \text{ yd}^3$$

$$\Delta V = \frac{9.63 - 2.29}{1 + 2.29} \; (240{,}000)$$

$$\Delta V = 535{,}440 \text{ yd}^3$$

Estimate volume required by dredged material in containment area

10. Use Equation 9:

$$V = V_i + \Delta V + V_{sd}$$

$$V_i = 240{,}000 \text{ yd}^3$$

$$\Delta V = 535{,}440 \text{ yd}^3$$

$$V_{sd} = \underline{60{,}000} \text{ yd}^3$$

$$V = 835{,}440 \text{ yd}^3$$

Determine maximum dike height

11. Foundation conditions limit dike heights to 10 ft.

Determine design area

12. Design area is equal to existing surface area:

$$A_d = 96 \text{ acres} \times 43{,}560 \text{ ft}^2/\text{acre}$$

$$A_d = 4{,}181{,}760 \text{ ft}^2$$

Evaluate volume available for sedimentation near the end of the disposal operation

13. Determine this value from:

$$V^* = H_{pd} A_d$$

$$= 2 \text{ ft } (4{,}181{,}760 \text{ ft}^2)$$

$$V^* = 8{,}363{,}520 \text{ ft}^3$$

Compare V^* and V_B

14. Since $V^* > V_B$, a 96-acre containment area will meet the suspended solids effluent requirement of 4 g/ℓ for the entire disposal operation.

Estimate thickness of dredged material layer

15. Determine this from:

$$H_{dm} = \frac{V}{A_d}$$

$$= \frac{835{,}440 \text{ yd}^3 \times 27}{4{,}181{,}760 \text{ ft}^2}$$

$$H_{dm} = 5.4 \text{ ft}$$

Determine required containment area depth

16. This depth is determined from:

$$D = H_{dm} + H_{pd} + H_{fb}$$

$$= 5.4 + 2 + 2$$

$$D = 9.4 \text{ ft}$$

Since $D = 9.4$ ft is less than the average basin depth of 10 ft, sufficient volume is available for the project.

Check weir length

17. The existing effective weir length L_e equals the weir crest length L for rectangular weirs:

$$L_e = 48 \text{ ft}$$

$$C_e = 4 \text{ g}/\ell$$

$$Q_i = 26.5 \text{ ft}^3/\text{sec}$$

$$H_{pd} = 2 \text{ ft}$$

18. With an average ponding depth within the containment area H_{pd} of 2 ft, the ponding depth at the weir D_p is estimated to be in excess of 3 ft, accounting for a dredged material surface which slopes toward the weir. Using Figure 22 from the main text, a 3-ft ponding depth at the weir requires an effective weir length of approximately 13 ft. The existing 24-ft weir length should therefore be adequate, but effluent suspended solids should be monitored periodically.

19. The remaining volume of 1,548,800 yd^3 in the existing containment area is sufficient to accommodate disposal of the 300,000 yd^3 of maintenance channel sediment into the basin under a continuous disposal operation. Since the required basin depth is less than the existing depth, no upgrading will be necessary to accommodate the first dredging operation. See the following example for determination of storage requirements for a second annual dredging.

Example II: Estimation of Additional Storage Capacity Requirements for an Existing Containment Area

Project information

20. General project data are identical with that used for the design method for freshwater sediments. Since the new disposal facility will not be available for 2 years, the available storage capacity must be determined for a second dredging. Estimates must therefore be made of the total settlement which will occur following placement of the first

dredging. The following data were determined in the previous example:

a. V_i = 240,000 yd^3 = volume of fine-grained channel sediment (annual requirement).

b. V_{sd} = 60,000 yd^3 = volume of sand (annual requirement).

c. ΔV = 535,440 yd^3 = change in volume of fine-grained sediments after disposal in the containment area.

d. e_o = 9.63 = average void ratio of dredged material at end of dredging.

e. G_s = 2.69 = specific gravity of solids.

f. D = 10 ft = average depth presently available as determined by survey.

g. A = 96 acres = surface area available for disposal where A = containment surface area requirement.

h. H_{dm} = 5.4 ft = thickness of dredged material layer at end of the dredging operation (for the first dredging).

Results of containment area field investigations

21. Field investigations were conducted at the containment area to define foundation conditions and to obtain samples for laboratory tests. Simplified foundation conditions as defined by the investigations are shown in Figure C4.

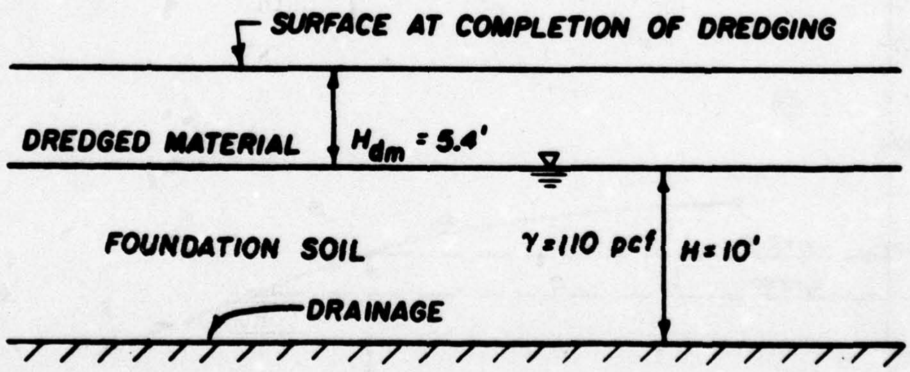

Figure C4. Foundation conditions

Results of laboratory tests

22. Consolidation tests were performed on samples of channel sediment and samples of the compressible foundation soils. Representative void ratio-log pressure and coefficient of consolidation-log pressure relationships were selected and are presented in Figures C5-C8.

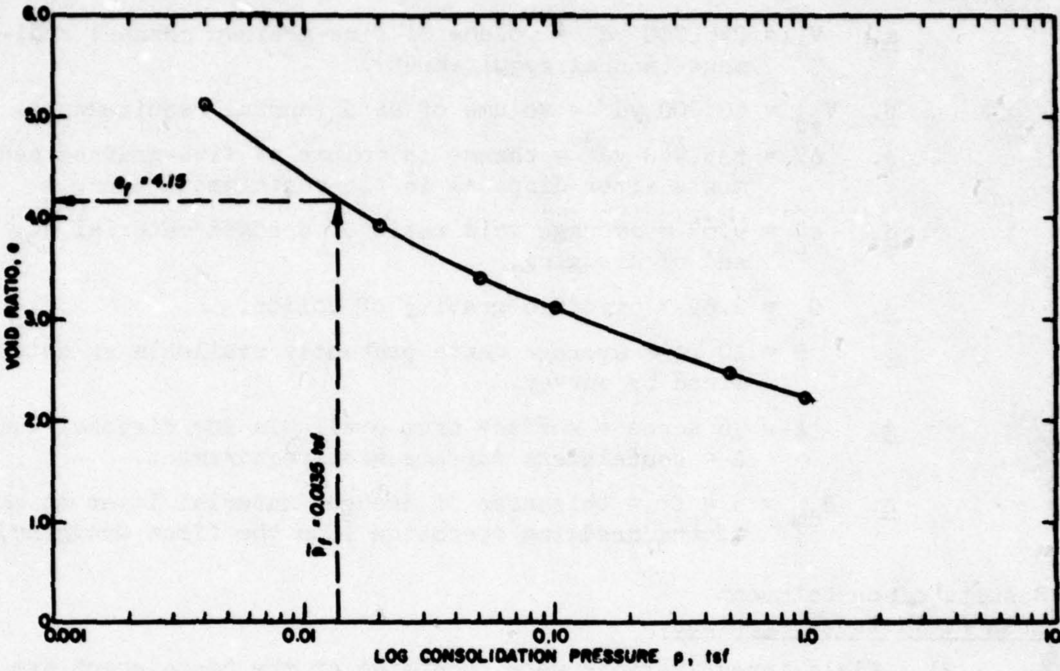

Figure C5. Void ratio-log pressure relationship for dredged material

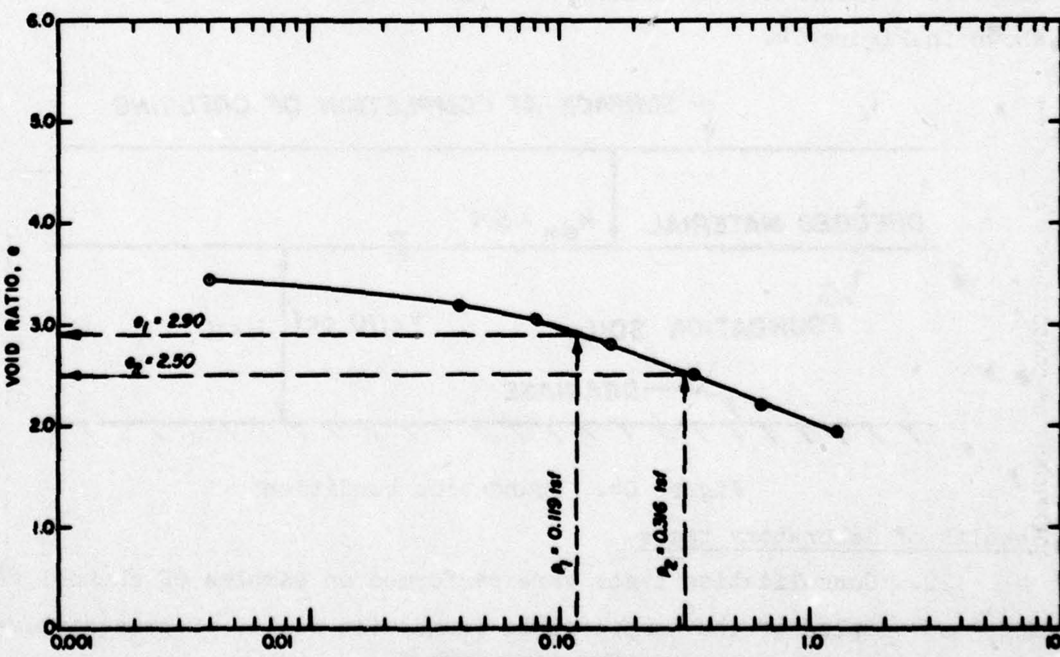

Figure C6. Void ratio-log pressure relationship for foundation soil

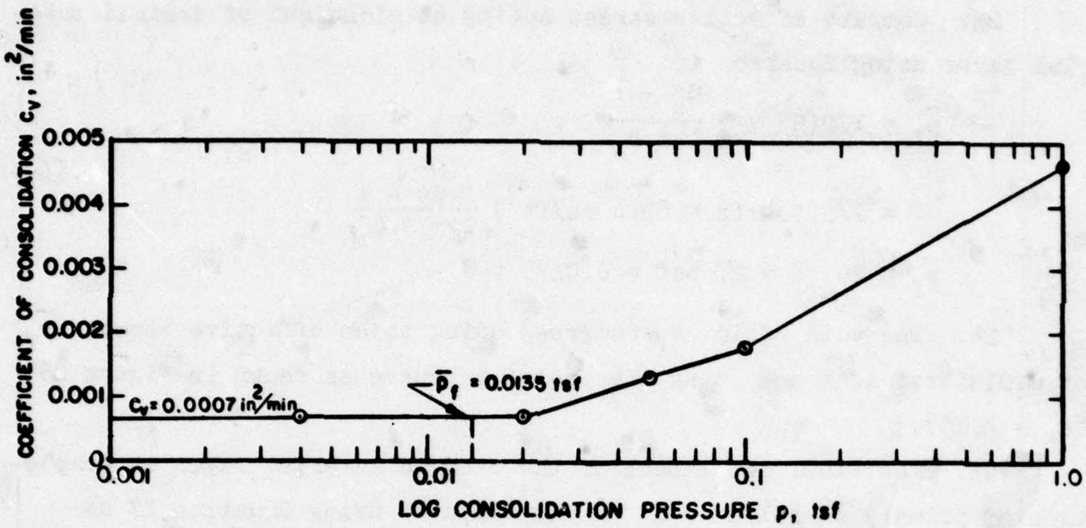

Figure C7. Coefficient of consolidation-log pressure relationship for dredged material

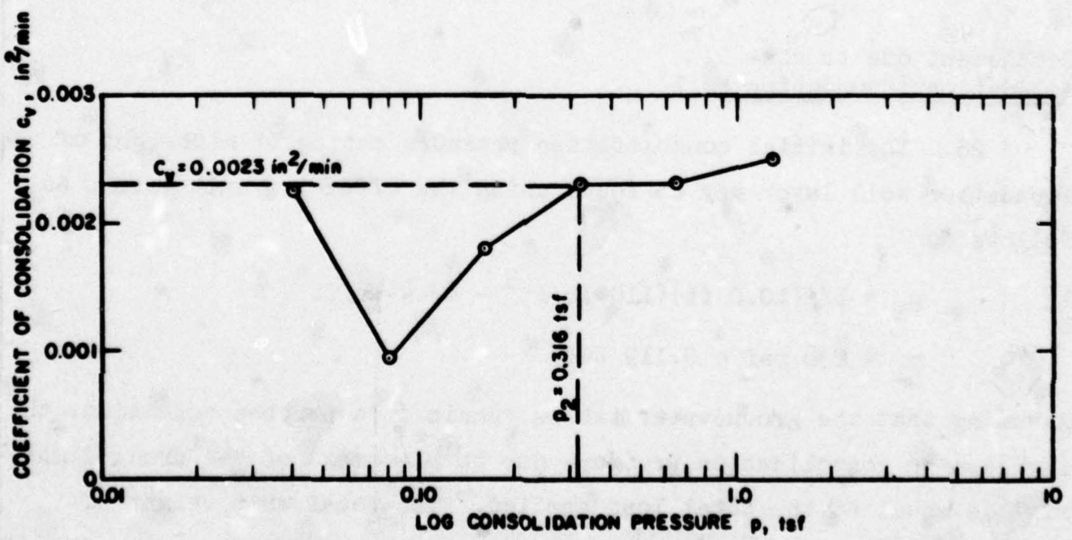

Figure C8. Coefficient of consolidation-log pressure relationship for foundation soil

Settlement due to consol-
idation (dredged material)

23. Compute effective stress acting at midheight of dredged material layer using Equation 16:

$$\bar{p}_f = 1/2(H_{dm}\gamma_w)\,\frac{G_s - 1}{1 + e_o}$$

$$= 1/2(5.4\ \text{ft} \times 62.4\ \text{lb/ft}^3)\,\frac{2.69 - 1}{1 + 9.63}$$

$$\bar{p}_f = 26.78 \approx 27\ \text{psf} = 0.0135\ \text{tsf}$$

24. The void ratio e_f corresponding to an effective stress $\bar{p}_f$ of 0.0135 tsf is found using the e-log p curve as shown in Figure C5 ($e_f = 4.15$).

25. The final settlement of the dredged material layer at completion of primary consolidation ΔH is computed using Equation 17 as follows:

$$\Delta H = H_{dm}\,\frac{e_o - e_f}{1 + e_o}$$

$$= 5.4\ \text{ft}\,\frac{9.63 - 4.15}{1 + 9.63}$$

$$\Delta H = 2.78\ \text{ft}$$

Settlement due to con-
solidation (foundation soil)

26. The initial consolidation pressure acting at midheight of the foundation soil layer may be found using the effective unit weight as follows:

$$p_1 = 1/2(10.0\ \text{ft})(110\ \text{lb/ft}^3 - 62.4\ \text{lb/ft}^3)$$

$$p_1 = 238\ \text{psf} = 0.119\ \text{tsf}$$

Assuming that the groundwater tables remain in a perched condition, the increase in consolidation pressure due to placement of the dredged material is equal to the total load applied. The total unit weight of dredged material is computed as:

$$\gamma = \frac{\gamma_w(e_o + G_s)}{1 + e_o}$$

$$\gamma = \frac{62.4(9.63 + 2.69)}{1 + 9.63}$$

$$\gamma = 72.32 \approx 73 \text{ pcf}$$

The increase in load Δp is then computed and is added to the initial consolidation pressure p_1 to obtain the total pressure p_2 acting at midheight of the foundation soil layer:

$$\Delta p = 5.4 \text{ ft}(73 \text{ lb/ft}^3) = 394 \text{ psf} = 0.197 \text{ tsf}$$

$$p_2 = p_1 + \Delta p = 0.119 + 0.197 = 0.316 \text{ tsf}$$

27. The void ratios e_1 and e_2 corresponding to pressures p_1 and p_2 are found using the e-log p curve in Figure C6 ($e_1 = 2.90$ and $e_2 = 2.50$).

28. The settlement of the foundation layer due to placement of dredged material ΔH is computed using Equation 18 as follows:

$$\Delta H = \frac{e_1 - e_2}{1 + e_1} (H)$$

$$= \frac{2.90 - 2.50}{1 + 2.90} (10 \text{ ft})$$

$$\Delta H = 1.03 \text{ ft}$$

Time-rate of consolidation

29. The coefficient of consolidation c_{vf} corresponding to the average effective stress $\bar{p}_f$ acting at midheight of the dredged material layer is found using Figure C7 to be $c_{vf} = 0.007 \text{ in.}^2/\text{min}$. Times required for the dredged material layer to reach various percentages of total consolidation are computed using Equation 19. Settlements for various times are computed using Equation 20. The resulting settlement versus time relationship is plotted in Figure C9. The time-rate of consolidation for the foundation soil was determined in a similar manner and the resulting settlement versus time relationship is also plotted in Figure C9.

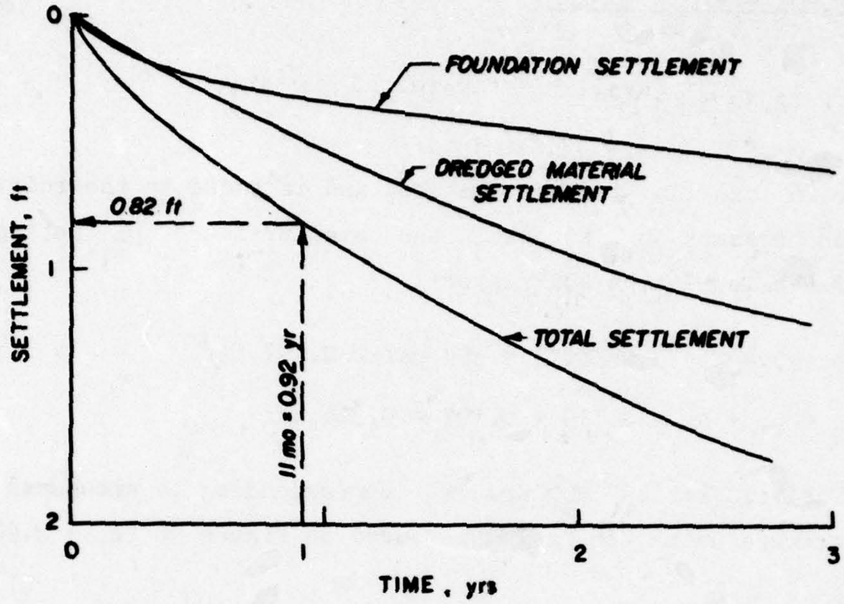

Figure C9. Settlement versus time relationships

Determination of
storage capacity requirement

30. The site will be required for the second dredging requirement 11 months following placement of the first dredging. The first dredging will be placed to an initial layer thickness of 5.4 ft during the 30-day dredging phase. Subsequent total settlement of the dredged material and foundation soil in the following 11 months (0.92 year) can be estimated using the settlement versus time relationship developed in Figure C9. Total settlement equals 0.82 ft.

31. The remaining height available for storage of the second dredging following settlement of the first dredging is determined as follows:

$$H_{dm} \text{ (available for second dredging)} = D - H_{pd} - H_{fb} - H_{dm} \text{ (first dredging)} + \text{total settlement first dredging}$$

$$= 10.0 - 2.0 - 2.0 - 5.4 + 0.82$$

$$= 1.42 \text{ ft}$$

The storage capacity available for the second dredging may then be computed as follows:

$$V = A_d H_{dm} \text{ (available for second dredging)}$$

$$= 96 \text{ acres} \times 43{,}560 \text{ ft}^3/\text{acre} \times 1.42 \text{ ft}$$

$$V = 5{,}938{,}099 \text{ ft}^3 = 219{,}930 \text{ yd}^3$$

32. In order to determine if the dikes must be raised for the second dredging, the available storage capacity must be compared with the storage capacity required to accommodate the total second dredging operation. This is most easily done by using the equivalent thicknesses of dredged material layers as it will result in a direct determination of the amount of dike raising necessary. Since the volume required for the total second dredging is equivalent to a thickness of dredged material H_{dm} of 5.4 ft and since the remaining height available is 1.42 ft, the dikes must be raised approximately 4 ft (5.4 - 1.42 = 3.98).

Example III: Containment Area Design Method for Saltwater Sediments

Project information

33. Fine-grained maintenance dredged material is scheduled to be dredged from a harbor maintained to a project depth of 50 ft. Channel surveys indicated that 500,000 yd^3 of channel sediment must be dredged. All available disposal areas are filled near the dredging activity, but land is available for a new site 2 miles from the dredging project. Since this harbor has to be dredged once every 2 years, the containment area must be designed to accommodate long-term disposal needs while meeting effluent suspended solids levels of 4 g/ℓ. In the past, the largest dredge contracted for the maintenance dredging has been a 24-in. pipeline dredge. This is the largest size dredge located in the area.

Results of laboratory tests

34. The following data were obtained from laboratory tests:

<u>a</u>. Salinity: 15 ppt.

<u>b</u>. Channel sediment in situ water content w : 92.3 percent.

c. Specific gravity G_s : 2.71.

d. Depth to solids interface as a function of time (settling column data) (see Table C5).

Table C5

Depth to Solids Interface (Feet) as a Function of Settling Time (Hours) (from Montgomery[8])

	Initial Suspended Solids Concentration, g/ℓ							
Time	55	73	120	143	163	215	243	310
0	0	0	0	0	0	0	0	0
0.25	0.230	0.145	0.065	0.050	0.065	0.026	0.010	--
0.50	0.390	0.290	0.165	0.090	0.138	0.050	0.020	0.005
0.75	0.530	0.435	0.270	0.170	0.210	0.075	0.030	--
1.0	0.620	0.535	0.360	0.230	0.276	0.100	0.040	0.009
2.0	0.690	0.635	0.490	0.420	0.430	0.225	0.080	0.020
3.0	0.740	0.680	0.535	0.475	0.467	0.340	0.100	0.025
4.0	0.770	0.700	0.555	0.505	0.495	0.365	0.122	0.035
5.0	0.805	0.710	0.580	0.530	0.510	0.390	0.140	0.050
6.0	0.820	0.730	0.585	0.553	0.515	0.410	0.160	0.070
7.0	0.830	--	--	0.565	--	0.440	0.188	--
8.0	0.840	--	--	0.575	--	0.440	0.188	--
10.0	--	--	--	0.595	--	0.459	0.212	--
20.0	--	--	--	0.655	--	0.522	0.259	0.190
30.0	--	--	--	0.690	--	0.564	0.292	0.250

e. Zone settling velocity as a function of concentration (see Table C6).

f. Zone settling velocity versus concentration curve (see Figure C10).

g. Calculations of solids loading values (use data given in Figure C10 to develop Table C7).

h. Solids loading versus solids concentration (use data in Table C7 to develop Figure C11).

i. Concentration as a function of time data (15-day settling column data) (see Table C8).

Table C6

Zone Settling Velocity as a Function of Suspended Solids Concentration (from Montgomery[8])

Concentration			Zone Settling Velocity
g/ℓ	%	lb/ft^3	ft/hr
55	5.2	3.4	1.238
73	6.8	4.5	0.571
120	10.8	7.5	0.410
143	12.7	9.0	0.245
163	14.3	10.2	0.282
215	18.5	13.5	0.133
243	20.7	15.2	0.041
310	25.8	19.5	0.015

Table C7

Calculations of Solids Loading Values* (from Montgomery[8])

Suspended Solids Concentration C			Zone Settling Velocity v_s	$S = v_s(C)$ Solids Loading
%	g/ℓ	lb/ft^3	ft/hr	$lb/hr - ft^2$
6.1	65	4	1.15	4.60
7.4	80	5	0.88	4.40
14.2	160	10	0.23	2.30
20.4	240	15	0.06	0.87
26.0	320	20	0.02	0.29
31.2	400	25	0.004	0.09

* Developed from curve shown in Figure C10.

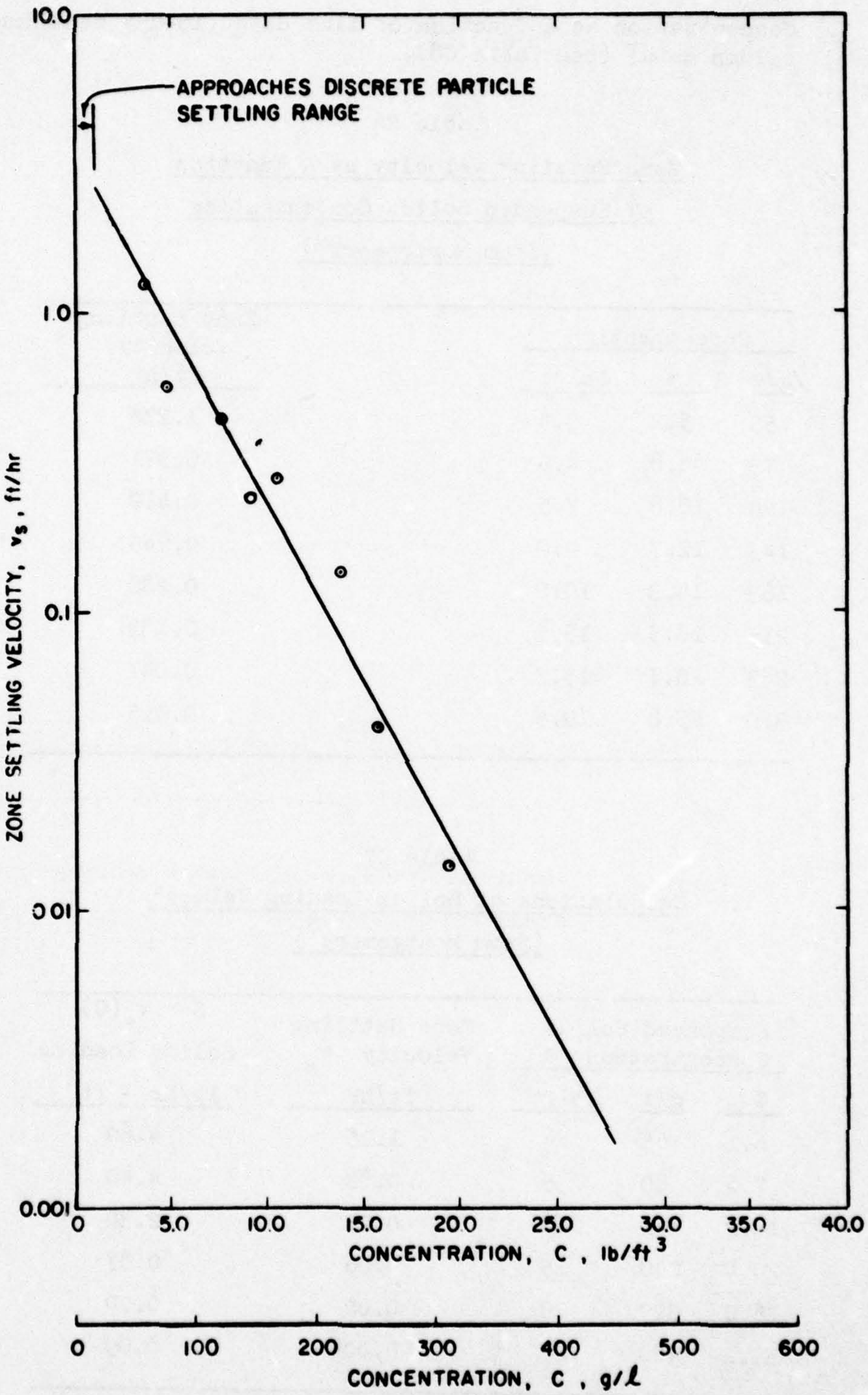

Figure C10. Zone settling velocity versus concentration

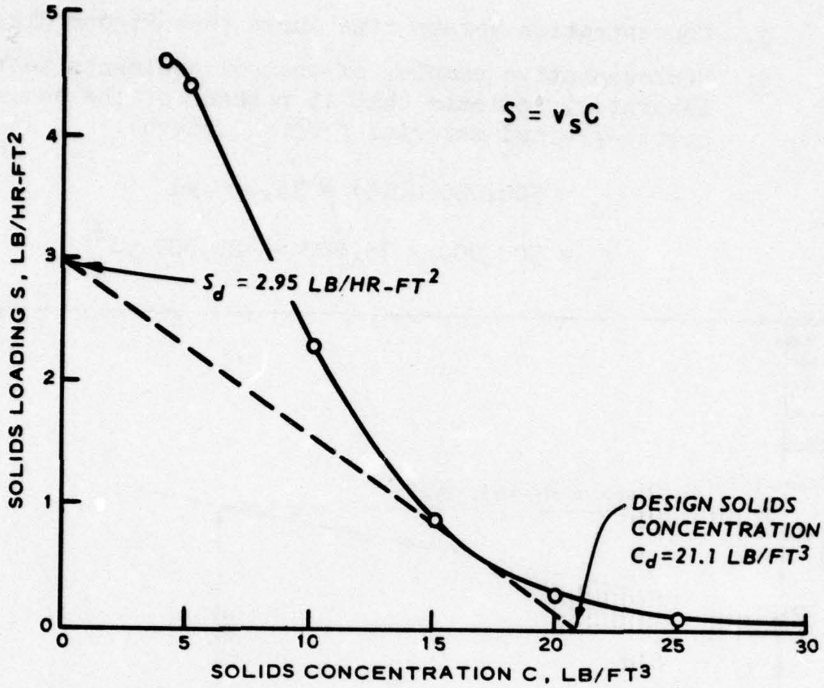

Figure C11. Solids loading versus concentration (from Montgomery[8])

Table C8

Concentration as a Function of Time

(from Montgomery[8])

Time days	Concentration g/ℓ
1	192
2	215
3	219
4	240
5	251
6	272
8	280
10	290
15	320

j. Concentration versus time curve (see Figure C12).

k. Representative samples of channel sediments tested in the laboratory indicate that 15 percent of the sediment is coarse-grained material (>No. 40 sieve).

$$V_{sd} = 500{,}000(0.15) = 75{,}000 \text{ yd}^3$$

$$V_i = 500{,}000 - 75{,}000 = 425{,}000 \text{ yd}^3$$

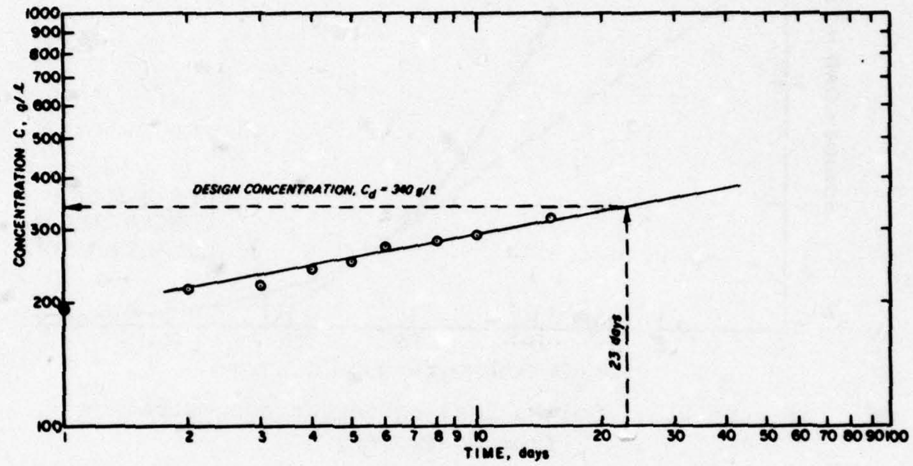

Figure C12. Concentration versus time (from Montgomery[8])

Compute design concentration

35. Compute this value as follows:

a. Project information:

(1) Dredge size: 24 in.

(2) Volume to be dredged: 500,000 yd^3.

b. Good records are available from past years of maintenance dredging in this harbor. They show that each time a 24-in. dredge was used, the dredge averaged operating 12 hours per day and dredged an average of 900 yd^3 per hour.

c. Estimate time of dredging activity:

$$\frac{500{,}000 \text{ yd}^3}{900 \text{ yd}^3/\text{hour}} = 556 \text{ hours}$$

operating time per day = 12 hours

$$\frac{556 \text{ hours}}{12 \text{ hours}} \approx 46 \text{ days}$$

d. Average time for dredged material consolidation:

$$\frac{46 \text{ days}}{2} = 23 \text{ days}$$

e. Design concentration is the concentration shown in Figure C12 at 23 days:

$$C_d = 340 \text{ g/l or } 21.1 \text{ lb/ft}^3$$

Compute area required for sedimentation

36. This value is computed as follows:

a. Construct operating line from design concentration (21.1 lb/ft^3) tangent to the loading curve (Figure C11). Design solids loading $S_d = 2.95 \text{ lb/hr-ft}^2$

b. Compute area requirement using Equation 3:

$$A = \frac{Q_i C_i}{S_d}$$

$$Q_i = A_p V_d$$

$$V_d = 15 \text{ ft/sec}$$

$$C_i = 9.2 \text{ lb/ft}^3$$

$$S_d = 2.95 \text{ lb/hr-ft}^2$$

$$Q_i = \frac{\left(\frac{24 \text{ in.}}{12}\right)^2 \pi}{4} \times 15 \text{ ft/sec}$$

$$= 47.12 \text{ ft}^3/\text{sec}$$

$$Q_i = 169{,}632 \text{ ft}^3/\text{hr}$$

$$A = \frac{169{,}632(9.2)}{2.95}$$

$$= 529{,}022 \text{ ft}^2$$

$$A = \frac{529{,}022}{43{,}560} = 12.14 \text{ acres}$$

c. Increase area by a factor of 2.25 (assumes containment area can be constructed with a length-to-width ratio of approximately 3):

$$A_d = 2.25(12.14 \text{ acres})$$

$$A_d = 27.3 \text{ acres}$$

Thus, the area required for sedimentation is 27.3 or 27 acres.

Estimate volume required for dredged material

37. This volume is estimated as follows:

a. Compute average void ratio using Equation 7:

$$e_o = \frac{G_s \gamma_w}{\gamma_d} - 1$$

$$G_s = 2.71$$

$$\gamma_w \approx 1000 \text{ g/}\ell$$

$\gamma_d = 340 \text{ g/}\ell$ = design concentration C_d (Figure C12)

$$e_o = \frac{2.71(1000)}{340} - 1$$

$$e_o = 6.97$$

b. Compute change in volume of fine-grained channel sediments after disposal in containment area using Equation 8.

$$\Delta V = V_i \frac{e_o - e_i}{1 - e_i}$$

Using Equation 2, $e_i = \dfrac{wG_s}{S_D}$

$$e_i = \frac{(92.3/100)(2.71)}{1.00}$$

$$e_i = 2.5$$

$$V_i = 425{,}000 \text{ yd}^3$$

$$\Delta V = \frac{6.97 - 2.50}{1 + 2.50}(425{,}000)$$

$$= 542{,}785 \text{ yd}^3$$

c. Estimate volume required by dredged material in containment area using Equation 9:

$$V = V_i + \Delta V + V_{sd}$$

$$V_i = 425{,}000 \text{ yd}^3$$

$$\Delta V = 542{,}785 \text{ yd}^3$$

$$V_{sd} = 75{,}000 \text{ yd}^3$$

$$V = 425{,}000 + 542{,}785 + 75{,}000$$

$$= 1{,}042{,}785 \text{ yd}^3$$

Estimate thickness of dredged material at end of disposal operation

38. Using Equation 10,

$$H_{dm} = \frac{V}{A_d}$$

$$= \frac{1{,}042{,}785 \text{ yd}^3(27)}{27 \text{ acres}(43{,}560)}$$

$$H_{dm} = 23.4 \text{ ft}$$

39. Because of foundation problems, dike heights are limited to 15 ft. Therefore, the area of the disposal area must be increased to accommodate the storage requirements. Use Equation 11 to determine allowable dredged material height:

$$D = H_{dm} + H_{pd} + H_{fb}$$

$$D = 15 \text{ ft}$$

$$H_{pd} = 2 \text{ ft}$$

$$H_{fb} = 2 \text{ ft}$$

$$H_{dm} = D - H_{pd} - H_{fb}$$

$$H_{dm} = 15 - 2 - 2$$

$$H_{dm} = 11 \text{ ft}$$

Compute new area requirement

40. Using Equation 10,

$$H_{dm} = \frac{V}{A_d}$$

$$A_d = \frac{1{,}042{,}785 \text{ yd}^3(27)}{11}$$

$$= 2{,}559{,}563 \text{ ft}^2$$

$$A_d = 59 \text{ acres}$$

Design for weir

41. The design parameters are:

$$Q_i = 47.12 \text{ ft}^3/\text{sec}$$

$$C_e = 4 \text{ g}/\ell$$

42. Using Figure 26, operating lines constructed at $Q_i = 47.12$ ft^3/sec and $C_e = 4$ g/ℓ indicate possible combinations of ponding depth and effective weir length required. Assuming that a 1-ft ponding depth at the weir is the minimum that could be allowed, a weir length of 35 ft is required. However, a ponding depth of 2 ft is recommended during the operation to provide a margin of safety. It should be noted that 59 acres is the minimum area required for storage of one dredging of 500,000 yd^3 and will not meet the long-term storage capacity requirement. See the following example for determination of the area required to meet this requirement.

Example IV: Estimation for Long-Term Capacity Requirements

Project information

43. General project data are identical with that for the design method for saltwater sediments. It is required that the containment area be designed for a service life of 10 years, accommodating a biannual dredging of 500,000 yd^3 of in situ channel sediment. The following data were determined in the previous example:

a. V_i = 425,000 yd^3 = volume of fine-grained channel sediments (biannual requirement).

b. V_{sd} = 75,000 yd^3 = volume of sand (biannual requirement).

c. ΔV = 542,785 yd^3 = change in volume of fine-grained sediments after disposal in the containment area.

d. G_s = 2.71 = specific gravity of solids.

e. H_{dm} (maximum) = 11 ft = thickness of the dredged material layer at the end of the dredging operation (maximum allowable thickness at end of last dredging operation due to foundation conditions).

f. Time required for each dredging = 46 days.

Results of containment area field investigations

44. Field investigations were conducted at the containment area to define foundation conditions and to obtain samples for laboratory tests. Simplified foundation conditions as defined by the investigations are shown in Figure C13.

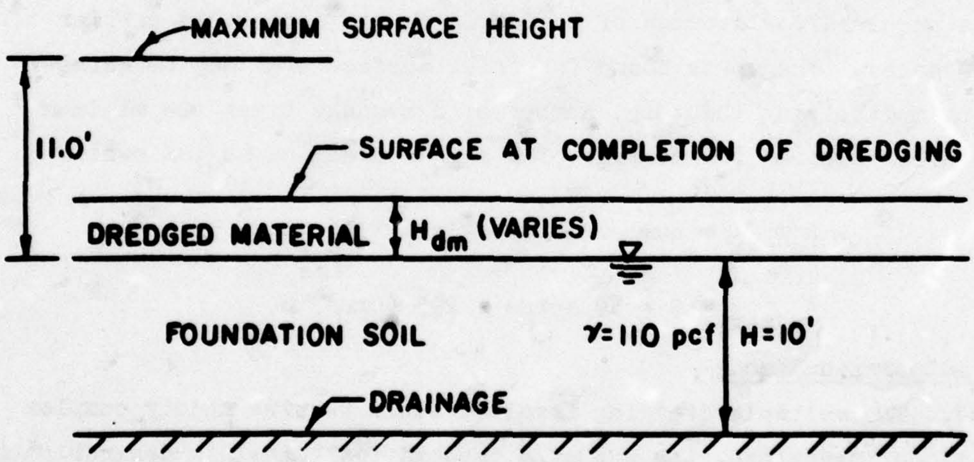

Figure C13. Foundation conditions

Results of laboratory tests

45. Consolidation tests were performed on samples of channel sediment and samples of the compressible foundation soil. Representative void ratio-log pressure and coefficient of consolidation-log pressure relationships were selected and are presented in Figures C5-C8.

Determination of
surface area required

46. Since the total dredging requirement equals five dredgings (10-year service life, biannual dredging), the minimum required surface area for one dredging will not meet the long-term requirement. Increasing the surface area in use will result in decreased initial dredged material layer thicknesses, allowing for a greater degree of consolidation between dredging operations. The optimum surface area for the long-term storage required cannot be directly determined since the magnitude of consolidation is dependent on layer thickness and loading, which is also a function of surface area. The solution must therefore be determined by trial.* A convenient method for selection of trials is to first establish an upper and lower bound on required surface area. The lower bound may be selected using the minimum required surface area for storage of a single dredging. The upper bound on surface area may be determined assuming no consolidation takes place. The area required for storage of one dredging was determined earlier to be 59 acres. The upper bound for trial surface area may be established by multiplying the total number of dredgings times the minimum surface area required for storage of a single dredging as follows:

$$A_{d\ max} = \text{number of dredgings} \times A_{d\ min}$$

$$A_{d\ max} = 5 \times 59 \text{ acres} = 295 \text{ acres}$$

Use of mathematical model

47. The multiple dredging involved would require unduly complex computations; therefore, the use of a mathematical model is desirable to estimate optimum surface area needed to meet the 10-year storage requirement. Trial runs of the model will allow selection of an optimum surface area. After examining the upper and lower bounds as described in the previous paragraph, the following trials were selected:

---

* If surface area was predetermined such as for an existing site or within available right-of-way limits, trial runs would not be required and the service life could be determined directly.

Trial No.	Trial Surface Area, acres	Corresponding Lift Thickness per Individual Dredging, ft
1	319	2
2	159	4
3	106	6

48. Johnson's model[22] was selected for use. Input data were coded for each trial in accordance with Johnson[22] using the project information stated earlier and laboratory test results shown in Figures C5-C8. Relationships for the coefficient of consolidation, coefficient of permeability, and coefficient of volume change versus consolidation pressure for dredged material required for the model were developed from the laboratory data and are shown plotted in Figures C14-C16.

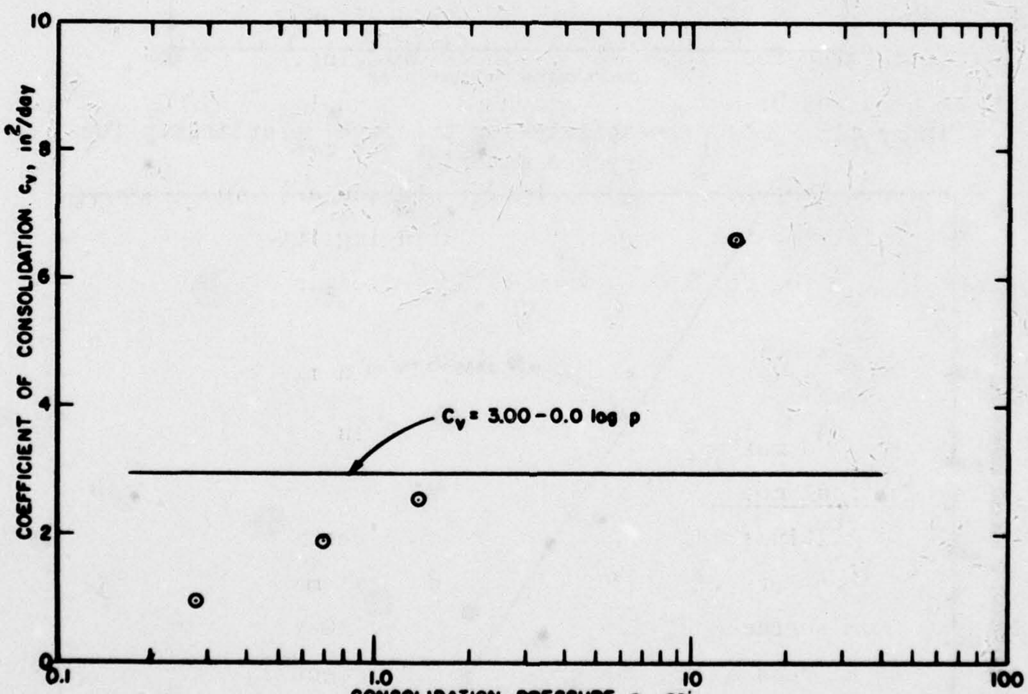

Figure C14. Coefficient of consolidation-log pressure relationship for dredged material

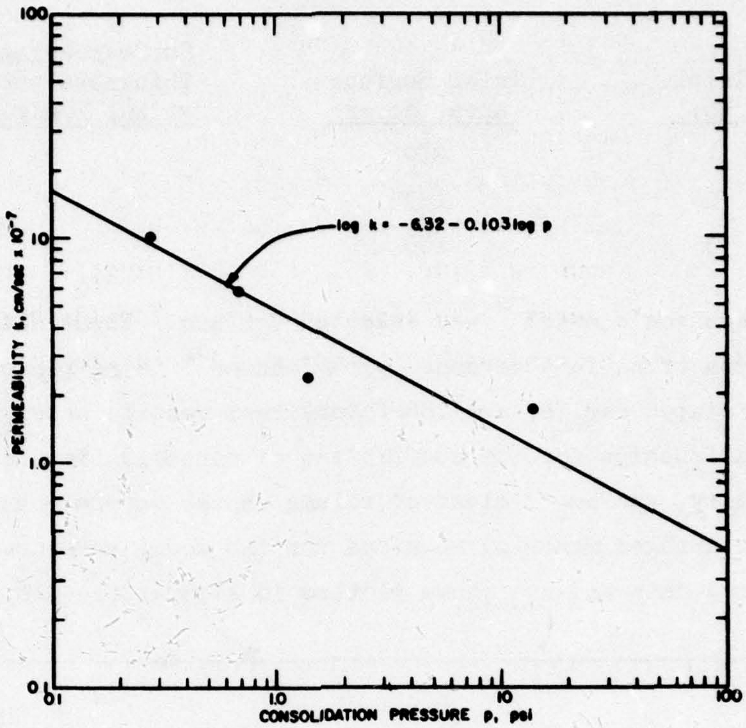

Figure C15. Log permeability-log pressure relationship for dredged material

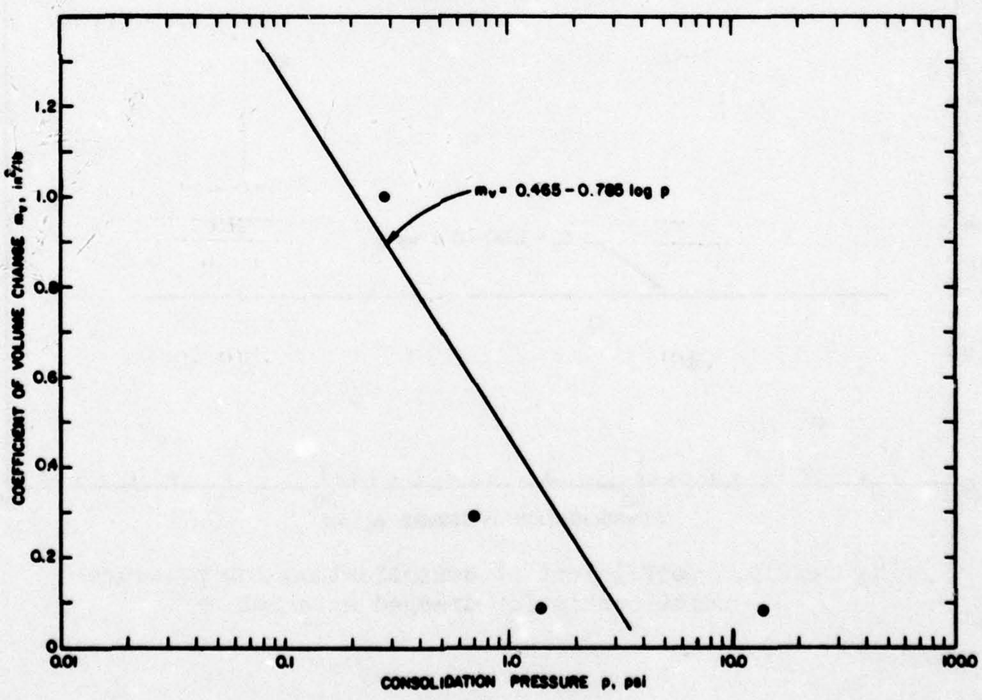

Figure C16. Coefficient of volume change-log pressure relationship for dredged material

49. Results of the trial model runs are interpreted in Figures C17-C19 which show projected surface heights versus time. The service life of the containment area for each trial run is also indicated in Figures C17-C19. The optimum surface area for a 10-year service life may then be estimated by plotting the surface area versus service life for all trials as shown in Figure C20. For this example, the design surface area is 255 acres. The containment area should therefore be constructed with dike heights of 15 ft, total enclosed area of 255 acres, and a length-to-width ratio of approximately 3:1.

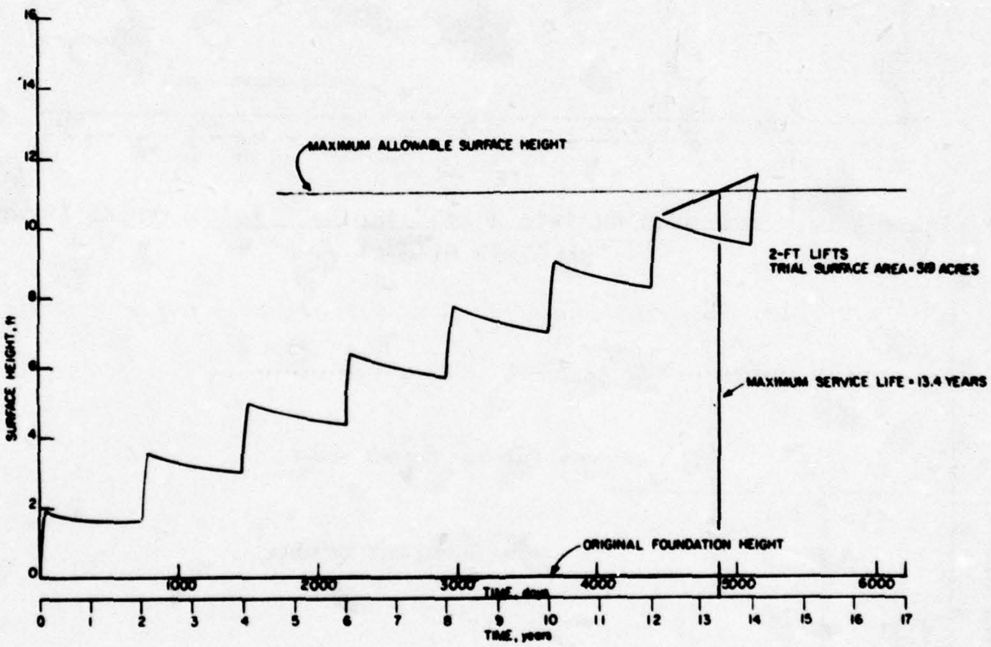

Figure C17. Projected surface height versus time for trial layer thickness of 2 ft

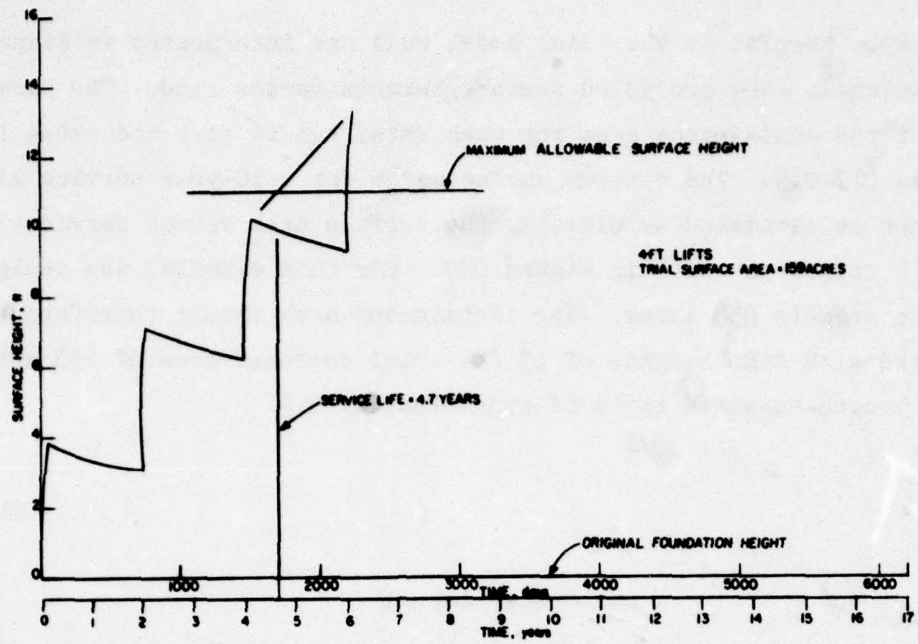

Figure C18. Projected surface height versus time for trial layer thickness of 4 ft

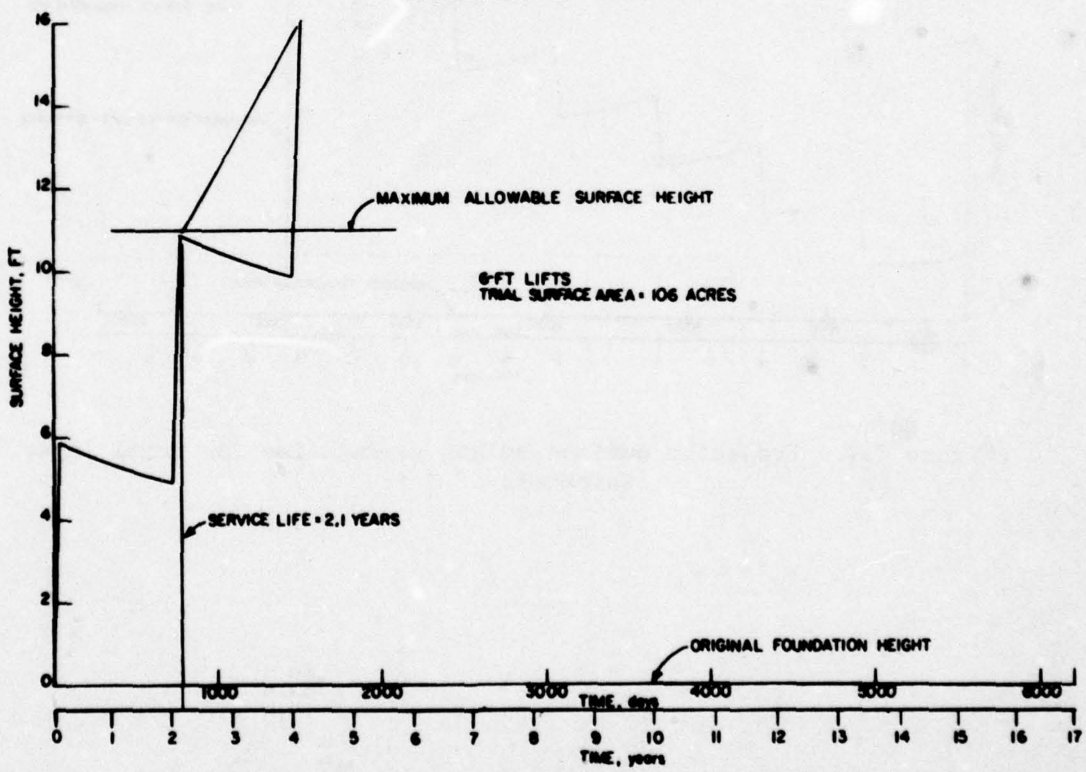

Figure C19. Projected surface height versus time for trial layer thickness of 6 ft

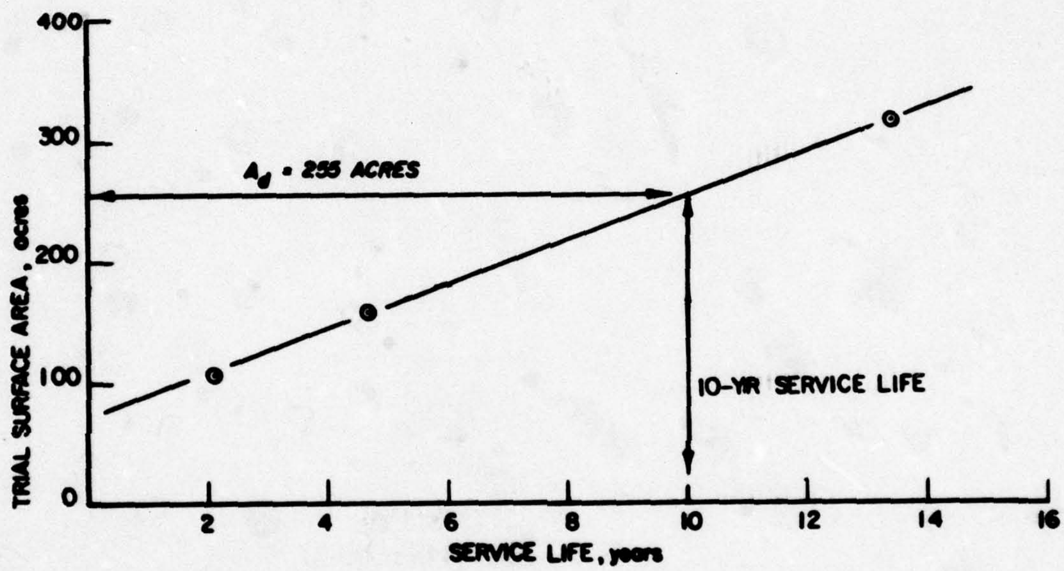

Figure C20. Trial surface area versus service life

APPENDIX D: SUMMARIES OF PERTINENT RESEARCH

1. This Appendix contains a synthesis of research conducted during the Dredged Material Research Program (DMRP) pertinent to designing, operating, and managing dredged material containment areas. A summary of the work units, study titles, and contributing contractor or in-house U. S. Army Engineer Waterways Experiment Station (WES) element is given in Table D1. The results of these efforts were used as a basis for the development of procedures for containment area design, operation, and management described in the main text of this report. The references cited should be consulted for more detailed information.

Work Unit No. 2C03--Practices and Problems in the Confinement of Dredged Material on Corps of Engineers Projects (Technical Report D-74-2)

2. Murphy and Zeigler[28*] evaluated confined dredged material disposal problems and practices as perceived by U. S. Army Corps of Engineers District offices in 1974. It was found that responsibility for containment area design and construction was sometimes left largely to the dredging contractor. The limits of available containment area right-of-way were usually designated on plans accompanying contract specifications. Commonly, the dike location and consequently the exact limits of the containment area were specified, but for some contracts only the general location of the disposal site was shown. In this case, no precise determination of disposal area size could be made beforehand, and accordingly, no accurate estimation of storage capacity, detention time, weir locations with respect to inflow pipe locations, and other factors affecting containment area efficiency could be made.

Design factors

3. Many Districts apply a design factor, sometimes called the "fluff" or "bulking" factor, to the volume of material to be dredged to determine the required storage capacity of the containment area.

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* Raised numers refer to similarly numbered items in the References at the end of the main text.

Table D1

Summary of DMRP Research Pertinent to Sizing and Operation of Containment Areas

DMRP Work Unit	Study/Report Title	Performing Organization	Report Designation
2C03	Practices and Problems in the Confinement of Dredged Material on Corps of Engineers Projects	Soils and Pavement Laboratory, WES	Technical Report D-74-2[28]
2C05	Investigation of Effluent Filtering Systems for Dredged Material Containment Facilities	Northwestern University	Contract Report D-76-8[29]
2C08	Mathematical Model for Predicting the Consolidation of Dredged Material in Confined Disposal Areas	Soils and Pavements Laboratory, WES	Technical Report D-76-1[22]
2C16	Investigation of Containment Area Design to Maximize Hydraulic Efficiency	B. J. Gallagher and Co.	Technical Report D-78-12[9]
2C19	Weir Design to Maintain Effluent Quality from Dredged Material Containment Areas	Environmental Laboratory, WES	Technical Report D-78-18[19]
4A16	Prediction of Stable Elevation for a Marsh Developed from Dredged Material	Massachusetts Institute of Technology	Internal Working Document D-77-15[30]
4A16A	Sizing of Containment Areas for Dredged Material	Massachusetts Institute of Technology	Technical Report D-77-21[31]
4A17A	Detailed Design for Dyke Marsh Demonstration Area	Environmental Laboratory, WES	Technical Report D-77-13[32]
5A13	Containment Area Management to Promote Natural Dewatering of Fine-Grained Dredged Material	Environmental Laboratory, WES	Technical Report D-77-19[24]
5A19	Prediction of Volumetric Requirements for Dredged Material Containment Areas	Environmental Laboratory, WES	Technical Report D-78-41[23]
5C11	Methodology for Design of Fine-Grained Dredged Material Containment Areas for Solids Retention	Environmental Laboratory, WES	Technical Report D-78-56[8]

4. Design factors in use prior to 1974 were probably more valid for predominantly coarse-grained sediments (particle size >0.074 mm), which exhibit discrete particle settling behavior in containment areas, than for fine-grained sediments, especially those containing significant quantities of colloidal size particles (<0.02 μ), which are governed by flocculent or hindered settling. The result is that the generally used factor of 2.0 for fine sediments may underestimate containment area storage capacity required to maintain adequate ponding depths.

5. The fact that many District specifications include a "shutdown clause," i.e., a requirement that the contractor cease disposal operations in the event of failure to meet effluent suspended solids requirements, indicates that sufficient storage capacity is sometimes not provided.

6. The difficulty associated with design factors for fine-grained sediments is also apparent when considering long-term gains in storage capacity. After disposal operations are completed, the sedimentation and self-weight consolidation of fine-grained dredged material and consolidation of foundation soils may result in large increases in available storage capacity that are not adequately considered by the design factors.

Containment efficiency

7. Although some sizing factors developed prior to 1974 considered the containment area retention time, no acceptable design procedure was available for determination of containment area efficiency. The efficiencies of active containment areas were found to vary considerably from over 99 percent to low values of approximately 75 percent. Districts have used various methods for increasing containment area efficiency, including use of alternating containment areas, placement of spur dikes, filtration of effluents, and intermittent operation. Weir designs have been largely based on hydraulic flow requirements and, in some cases, rule of thumb.

Work Unit No. 2C05--Investigation of Effluent Filtering Systems for Dredged Material Containment Facilities (Contract Report D-76-8)

8. Krizek, FitzPatrick, and Atmatzidis[29] conducted a study to evaluate effluent filtering systems for containment areas. A necessary part of the study was the development of preliminary techniques for determining the concentration and gradation of containment area effluents. A refined application of discrete settling theories for containment design was proposed. An attempt was made to use Hazen's sedimentation theory to estimate the proportion of particles of different sizes that will be retained by discrete sedimentation in a containment area. Equations and nomograms were then developed for estimating concentration and gradation of suspended solids in containment area effluents.

9. The discrete settling behavior of dredged material as proposed in the study is valid for coarse-grained particles. However, the sedimentation of fine-grained material is controlled by flocculent or zone settling behavior.

Work Unit No. 2C08--Mathematical Model for Predicting the Consolidation of Dredged Material in Confined Disposal Areas (Technical Report D-76-1)

10. Johnson[22] developed a procedure for determining the volume-time relationships of dredged material and foundation soils in flooded containment areas. Volume-time relationships were explored by examination of sedimentation and consolidation theories, methods were developed for determination of both sedimentation of dredged material and consolidation of dredged material and foundation soils, and a computer model was developed to determine the reduction in volume or settlement from primary consolidation of dredged material and foundation soils. Additional information regarding use of the model is contained in Poindexter.[33]

Model capabilities

11. The settlements of dredged material and foundation soil are calculated by the model on the basis of the dissipation of excess pore

water pressure according to standard theory of one-dimensional (1D) primary consolidation. A special explicit finite difference numerical technique was applied to solve the 1D differential equation for primary consolidation. The numerical technique permits versatile boundary conditions that may be reasonably representative of actual field conditions for confinement of dredged material. The model contains provisions to permit settlement predictions for (a) dredged material that increases in thickness with time from periodic disposal operations, and (b) variations in time intervals between disposal operations.

12. The computer code was prepared for time-sharing on the WES GE-600 computer but can be easily converted to other automatic data processing systems. The code is capable of computing the excess pore pressure distribtuion, average degree of consolidation, and settlement of dredged material and layered foundation soil strata of flooded containment areas. Time intervals for placement of dredged material during a single disposal operation and between disposal operations may be varied. The consolidation parameters of the dredged material may be input as a function of the effective stress to permit improved simulation of actual field conditions. The consolidation parameters of the foundation soils are assumed constant.

13. A variety of dredging operations spaced at various time intervals may be handled by the code in a single computer run provided that the dredged material being placed is homogeneous with identical consolidation parameters. The consolidation behavior of dredged material and foundation soils may be calculated for a number of dredging operations involving different dredged material if (a) a single computer run of the code is used to solve for the consolidation behavior of the soil system for each disposal operation, and (b) the initial excess pore pressures are input from a data file. The dredged material deposited during the previous disposal operation may be treated as the surface layer of foundation soils (with constant consolidation parameters) for the current disposal operation.

Data requirements

14. Certain information relating to the disposal area must be

available before the model can be utilized. The surface area of the containment site is required for determination of the initial lift thicknesses for each dredging operation. The freeboard and ponding requirements and maximum allowable dike height must be known so that they can be considered in the initial development of the 1D finite difference mesh.

15. Characteristics of the dredging operation must be available. The in situ water content and volume of material to be dredged are required for the analysis. The rate (at the in situ water content) at which the material is discharged into the containment area and the fraction of solids in the slurry are needed and may be obtained from the production characteristics of the dredge to be used. In order for the long-term capacity to be determined, the number of times dredged material is to be deposited and the time interval for each cycle must be known or estimated from past experience.

16. Consolidation properties of the dredged material and each compressible foundation soil must be determined before the settlement due to sedimentation and/or primary consolidation can be estimated. These required properties include the coefficient of permeability, coefficient of consolidation, and coefficient of volume change. In order to determine the consolidation parameters, a standard consolidation test must be performed on each compressible soil strata present in the containment area foundation; a consolidation test is also necessary to determine the consolidation parameters for the dredged material. The coefficient of permeability can be determined by running a permeability test either independently or in conjunction with the consolidation test, or the coefficient of permeability may be calculated from the consolidation data.

17. Additional information needed for characterization of the dredged material includes the specific gravity of solids and the average particle diameter. The dry density is also needed but it may be calculated using the water content and specific gravity. The void ratio-time relationship developed from the slurry sedimentation test provides the remaining input parameters required for use of the model.

18. The type of drainage that will occur in the foundation soil system must be determined. Double drainage occurs when water can drain from the surface of the dredged material and from the bottom of the foundation soils. Surface drainage exists when the foundation soils are relatively impervious and water can escape only from the surface of the dredged material. Whether double or surface drainage will occur is dependent upon the relative permeabilities of the materials present at the site.

Results obtained

19. The output data from the program are printed in tabular form. The average degree of consolidation of both the dredged material and the foundation soil are given along with the time required to reach that percentage of consolidation. The amount of settlement of the dredged material and the foundation soil are also listed. The output data include the excess pore water pressure which is calculated for various locations throughout the depth analyzed.

Work Unit No. 2C16--Investigation of Containment Area Design to Maximize Hydraulic Efficiency (Technical Report D-78-12)

20. B. J. Gallagher and Co.[9] developed general guidelines for the planning, design, and management of dredged material containment areas to obtain maximum hydraulic efficiency and removal effectiveness. The investigation concentrated on the hydraulic properties of containment areas and their appurtenances, which affect the removal and retention of suspended solids. The investigation included an extensive literature review, interviews with key personnel from various Corps Districts, field studies, and the development of computer models for synthesizing flow patterns in disposal areas. Model studies were used in estimating overall hydraulic efficiencies of various containment shapes, inflow/outflow locations, and spur dike configurations. All of this information and data were then integrated to produce recommendations for design of containment areas to obtain maximum hydraulic efficiency.

21. The model studies generally indicated that square or

irregularly shaped areas have a hydraulic efficiency of roughly 50 percent. An additional 10 percent gain in efficiency is realized for each length-to-width ratio higher than 1. For example, if the length-to-width ratio is 4, a 30 percent gain in efficiency is realized, resulting in a total efficiency of 80 percent. In all cases the estimated hydraulic efficiency should not exceed 90 percent.

22. The relative locations of the inflow pipe and the outflow weir were found to have a significant effect on the hydraulic efficiency of the containment area by directly influencing the effective area and the occurrence and degree of short-circuiting. The effect of multiple weirs on the flow pattern is slightly better than the effect of a single weir of the same total length and could be advantageous for areas with high width-to-length ratios. Multiple weirs would be preferred if a single weir of long length was not practical.

23. Variation of the weir length has some effect on the flow pattern, but this is pronounced only in the vicinity of the weir. The disadvantages of short weir lengths are that (a) inactive surface area develops at the corners of the basin on the side of the weir, and (b) flow velocities in the vicinity of the weir are high resulting in possible resuspension. This effect would be significant for areas with a high width-to-length ratio.

24. Consideration was given to the use of spur dikes to increase the length-to-width ratio and improve hydraulic conditions in a disposal area. Flow patterns were determined for various spur dike configurations. Short-circuiting was reduced for all configurations, but the effect was greater for longer spur dikes. However, to avoid excessive flow concentration and increased flow velocities through the spur dike openings, the length of the spur dikes should be approximately three fourths the length of the parallel basin side. One or two spur dikes should usually be sufficient and three or four should be the maximum number used. A minimum length-to-width ratio of approximately 5 should be provided for the flow pattern if possible. A spur dike should not be located close to the weir as it will have a detrimental effect on the hydraulic efficiency of the basin because higher flow velocities will occur and there will be a

possible resuspension of bottom sediment in the vicinity of the weir.

Work Unit No. 2C19--Weir Design to Maintain Effluent Quality from Dredged Material Containment Areas (Technical Report D-78-18)

25. Walski and Schroeder[19] evaluated the relationship between weir design and effluent suspended solids and developed a procedure for designing and operating weirs. An extensive literature review was conducted to determine if mathematical models were available to predict the depth of the withdrawal zone or the required ponding depth and the velocity profile for weirs. Both stratified flow selective withdrawal models and sediment transport models were considered for predicting the withdrawal depth. While theoretical descriptions of flow conditions similar to those encountered in containment areas were available, no field data could be found in the literature describing the withdrawal depth or the velocity profile in dredged material containment areas.

26. A field study program was therefore formulated to provide the necessary data for development of a design procedure. Data were collected at several active containment areas to determine the magnitude of the weir's effect on the effluent quality. The effluent suspended solids concentration was measured for various weir flows. Increasing the head resulted in increases in the unit flow (flow per unit width of weir), velocities, and depth of the withdrawal zone, resulting in increased effluent suspended solids. Therefore, it was clear that the head over the weir or, similarly, the weir length had a strong influence on the effluent quality.

27. Data collected at the field sites were also used as input data for evaluation and verification of models available in the literature. Required information included velocity, concentration and density profiles; flow, depth, weir length, head over the weir, and velocity of flow over the weir; and grain size, specific gravity, and angle of repose of the dredged material. Much of the information was available in the literature; the exceptions were concentration and density profiles representative of dredged material containment areas. Concentration profiles for

different dredged material and site conditions were therefore determined for all field sites. Other data, including the flow velocity profile, weir length, depth of withdrawal zone, head over the weir, velocity over the weir, and specific gravity of the dredged material, were also taken.

28. A model was selected and verified for use in development of design guidelines based on evaluations of the field data. The model selected was developed by Bohan and Grace[34] and is called the WES selective withdrawal model. A computerized code of the model which calculates the velocity profile based on the weir type and density profile is available. It is also capable of using any form of density stratification and predicting the effluent solids concentration. This model was deemed to offer the best potential for use in the design procedure. The weir design procedures and guidelines for weir operation were developed using the WES selective withdrawal model and verified by limited observed field data.

Work Unit Nos. 4A16 and 4A16A--Sizing of Containment Areas for Dredged Material (Internal Working Document D-77-15 and Technical Report D-77-21)

29. A volumetric sizing procedure based on laboratory tests was developed by the Massachusetts Institute of Technology (MIT) in 1975[30] for application in marsh development activities. A methodology was later developed by Lacasse, Lambe, and Marr[31] adapting the laboratory procedures to volumetric sizing of containment areas.

30. Laboratory testing procedures as developed in the study produced a composite void ratio/compression relationship for dredged material based on results of column sedimentation tests and slurry consolidation tests performed in a special constant rate of strain apparatus. Results of the tests were used to predict void ratio and effective stress relationships for the dredged material using accepted soil mechanics principles.

31. Field void ratio data gathered from several containment areas were in close agreement with computed values. The studies generally indicated that correlation of field void ratio distributions and effective

stress relationshiops before and after dredging could be satisfactorily predicted using the results of laboratory tests.

Work Unit No. 4A17A--Detailed Design for Dyke Marsh Demonstration Area (Technical Report D-77-13)

32. Palermo and Zeigler[32] developed a volumetric sizing procedure which relies on a full height sedimentation test and conventional consolidation tests. The procedure was developed for a specific marsh development project but has application for general containment area sizing.

33. The laboratory testing procedure involved use of a sectioned, 8-in.-diam sedimentation column equal in height to the expected average thickness of the dredged material at the completion of dredging. A multilift sedimentation test was used to simulate sedimentation behavior. Standard consolidation specimens were then removed directly from the column and conventional consolidation tests were performed. Results of these tests were used to predict field sedimentation and self-weight consolidation behavior. The study indicated that conventional consolidation tests were satisfactory for use in predicting self-weight consolidation behavior of dredged material.

Work Unit No. 5A13--Containment Area Management to Promote Natural Dewatering of Fine-Grained Dredged Material (Technical Report D-77-19)

34. Bartos[24] investigated general containment area management as a technique for promoting the natural dewatering of fine-grained dredged material. Guidelines were developed for containment area management activities performed before, during, and after the dredging operation.

35. It was determined that activities which should be accomplished before the dredging operation are dependent upon the condition of the dredged material (if any) present in the containment area and upon the method(s) being considered to dewater the subsequent lift. Such activities may include clearing and leveling the site, productive use of

existing dredged material, and relocating or adding inlets or weirs to the containment.

36. During the dredging operation, management activities may include surface water management, manipulation of inlets and weirs, placement of dredged material in thin lifts, and separation of coarse-grained material. Management activities after completion of dredging should be concentrated on effective drainage of surface water and implementation of dredged material dewatering and disposal area reuse management.

Work Unit No. 5A19--Prediction of Volumetric Requirements for Dredged Material Containment Areas (Technical Report D-78-41)

37. Hayden[23] developed a procedure for determining the volumetric requirements of a confined disposal site being filled with fine-grained dredged material slurry. A new prediction methodology was formulated utilizing a modified consolidation theory and standard weight-volume relationships used in geotechnical engineering. The volume increase predicted by the proposed methodology was then correlated to the rate of volume increase measured under field conditions. A computer program was developed to evaluate the effect of various input variables on the gain in available storage volume.

Model capabilities

38. The computer program calculates the variation in storage volume with time for specific confined disposal sites. The analysis begins with initiation of the dredging process and terminates either when an equilibrium volume has been reached or when additional dredged material has been placed in the containment area. Therefore, a new computer run is required each time additional dredged material is placed in the disposal area.

39. The computer program was prepared for the WES GE-600 computer, but can be converted to other automatic data processing systems. The program is capable of computing the minimum dike height necessary to contain the dredged material, determining an operational scheme for maximum drainage efficiency, and developing an optimum dredging schedule. Both the

sedimentation-consolidation characteristics of the dredged material and consolidation of the foundation soils are included in the computer analysis. The increase in available storage volume resulting from desiccation of the dredged material by ambient climatological conditions and from implementation of various dewatering techniques is computed.

40. Various subsurface conditions may be handled by the program. The capability exists for analyzing the foundation materials for: (a) a water table continuous throughout the foundation and dredged material, (b) a perched water table within the foundation, or (c) no foundation consolidation. Calculations for foundation consolidation are based upon a one-dimensional consolidation approach.

41. The program is capable of implementing mathematically the dewatering technique(s) specified. The options available include: (a) natural evaporation, (b) progressive trenching to enhance natural evaporation, (c) implementation of some artificial dewatering technique(s), and (d) a combination of an artificial dewatering technique(s) and progressive trenching.

Data requirements

42. Specific laboratory test results must be available in order for the program to be utilized. Information necessary from the column sedimentation-consolidation test includes specific gravity of solids, percent solids by weight, and the slurry height-time relationship developed during the test. The remolded consolidation test results which are required include both the void ratio at 100 percent primary consolidation and the coefficient of consolidation corresponding to the applied effective stress.

43. Characteristics of the dredging operation and the disposal site must be known. In situ channel sediment properties which are required include specific gravity, water content, and volume to be dredged. Also, the specific gravity, void ratio, and percent by weight of in situ material with an average grain size diameter greater than 0.1 mm are needed. The plastic limit of the fine-grained portion of the sediment must be determined. For the slurry, the percent solids by weight and the velocity of discharge, as well as the discharge pipe

diameter, are needed. The number of drainage surfaces for the dredged material must be known. For volumetric calculations and effluent quality control, the surface area of the site, maximum allowable discharge head, ponded head, minimum allowable freeboard, and width of stop-logs are required.

44. Dewatering information which is required includes the method of dewatering, increase in effective stress resulting from artificial dewatering technique(s), and natural drainage efficiency of the disposal site. The month in which dredging is initiated and the total number of months between dredging cycles are also necessary.

45. Climatological data are needed for all 12 months of the year. For each month, the total potential evaporation and total potential rainfall are required.

46. The type of foundation consolidation must be specified. The total number of foundation strata at the site and the number of individual strata located between the base of the dredged material and any perched water table are required. For each foundation strata, the applied effective stress and the corresponding void ratio and coefficient of consolidation must be determined. Additionally, the specific gravity, void ratio, layer thickness, water content, and number of drainage surfaces are required for each strata.

Results obtained

47. The output data include a summary of the input data and the desired computational results. Tables, graphs, and descriptive statements are used to present the results. Summaries of output data necessary for design and operation of disposal sites as well as graphs depicting various time relationships of surface elevation and desiccation crust formation are printed.

Work Unit No. 5C11--Methodology for Design of Fine-Grained Dredged Material Containment Areas for Solids Retention (Technical Report D-78-56)

48. Montgomery[8] investigated dredged material settling characteristics, dredged material sedimentation processes, applicability of

prevailing sedimentation theories for the design of dredged material sedimentation basins, and the influence of existing disposal operation practices on sedimentation. The purpose of this investigation was to develop design and operational guidelines for dredged material sedimentation basins. The design and operational guidelines were aimed at providing dredged material sedimentation basins that could accommodate continuous flow while meeting effluent suspended solids requirements.

49. Active dredging projects were selected for field studies and sediments from each dredging environment were sampled and tested in the laboratory. Discharges from dredge pipelines were sampled at regular time intervals and suspended solids were determined. The data show that concentrations from dredge pipelines vary greatly with time. Thus, determinations based on only a few samples will not reflect accurate disposal concnetrations. A good average disposal concentration for hydraulic pipeline dredges was determined to be 145 g/ℓ (13 percent by weight).

50. The laboratory studies determined that two types o sedimentation occur in the fine-grained dredged material sedimentation basins. Flocculent settling is characteristic of freshwater dredging disposal activities, and the saltwater dredging disposal activities are characterized by zone settling. Laboratory tests indicated that settling properties determined from settling tests on channel sediments to be dredged were representative of the settling properties of the sediments as they were discharged into disposal areas from the dredge pipeline.

51. Laboratory tests were performed to determine the most effective settling column size. Tests were conducted in settling columns varying in diameter from 2.4 to 36 in. and varying in height from 1.12 to 8 ft. The recommended column determined from these tests is 8 in. in diameter and the settling test should be conducted at the expected settling depth of the actual sedimentation basin with 6 ft being a minimium practical depth.

52. Two design methods were developed for designing the sedimentation basins, one for a saltwater dredging environment and one for a freshwater dredging environment. These methods were adapted to the dredging operation from existing sedimentation design guidelines.

Design procedures were developed providing a sound theoretical approach so that practicable dredged material sedimentation basins can be designed that will perform in a more predictable manner without being grossly oversized or undersized.

53. Montgomery[35] reported on the results of a limited amount of field work aimed at verifying the design methodology. The design procedures recommended were found to provide design estimates that agreed closely with actual field values. However, additional cases should be evaluated for full verification of these procedures.

APPENDIX E: NOTATION

A	Containment surface area requirement, ft^2
A_d	Design surface area, ft^2
A_p	Cross-sectional area of dredge pipe, ft^2
c_v	Coefficient of consolidation, $in.^2/min$
c_{vf}	Coefficient of consolidation corresponding to average effective stress, $in.^2/min$
C	Suspended solids concentration, g/ℓ or lb/ft^3
C_d	Design solids concentration, g/ℓ or lb/ft^3
C_e	Suspended solids concentration of dredged material effluent, g/ℓ or lb/ft^3
C_i	Suspended solids concentration of dredged material influent, g/ℓ or lb/ft^3
CH	Clay of high plasticity
CL	Clay of low plasticity
d	Depth, ft
D	Required dike height, ft
D_p	Ponding depth at weir, ft
D_w	Withdrawal depth, ft
e_f	Average void ratio at completion of primary consolidation
e_i	Average void ratio of in situ sediment
e_o	Average void ratio of dredged material at completion of dredging
e_1	Void ratio of soil layer at pressure p_1
e_2	Void ratio of soil layer at pressure p_2
G_s	Specific gravity of solids
h	Depth of flow over the weir, ft
H	Initial thickness of layer, ft
H_d	Average length of drainage path, ft
H_{dm}	Thickness of dredged material layer at the end of the dredging operation, ft
H_{fb}	Height of freeboard in containment area, ft
H_{pd}	Ponding depth in containment area, ft
H_s	Static head over the weir, ft

J	Length of weir perpendicular to the dike, ft
k	Coefficient of permeability, cm/sec
L	Weir crest length, ft
L_e	Effective weir length, ft
L_s	Length of one side of a square shaft weir, ft
LL	Liquid limit of soil
m_v	Coefficient of volume change, in.^{2}/lb
MH	Silt of high plasticity
ML	Silt of low plasticity
n	Number of effective sides of a shaft-type weir
OC	Organic content, percent
p	Consolidation pressure or overburden pressure, lb/ft^2
$\overline{p}_f$	Average effective stress acting at midheight of the layer of dredged material, lb/ft^2
PI	Plasticity index of soil
PL	Plastic limit of soil
Q	Flow rate, ft^3/sec
Q_e	Clarified effluent rate, ft^3/sec or gal/min
Q_i	Dredged material influent rate, ft^3/sec or gal/min
R	Percent solids removal
S	Solids loading, lb/ft^2-hr
%S	Percent solids by weight
S_d	Design solids loading, lb/hr-ft^2
S_D	Degree of saturation (equal to 100 percent for sediment)
t	Time
t_u	Time to reach degree of consolidation U, min
t_w	Weir thickness
T	Theoretical detention time, min or hours
T_d	Design detention time, min or hours
T_u	Time factor for degree of ultimate consolidation U
U	Degree of ultimate consolidation, percent
v_s	Zone settling velocity, ft/hr

V	Volume of dredged material in the basin at the end of the dredging operation, ft^3
V^*	Volume available for sedimentation near the end of the disposal operation, ft^3
V_A	Apparent volume of settled solids, litres
V_B	Containment area volume required for meeting suspended solids effluent requirements, ft^3
V_d	Velocity of dredge discharge, ft/sec
V_i	Volume of in situ sediment to be dredged, ft^3
V_I	Volume of interstitial water, litres
V_S	Volume of solid particles, litres
V_{sd}	Volume of sand, ft^3
V_T	Total volume of sample, litres
w	Water content, percent
W_S	Weight of solids in sample, g
W_T	Total weight of sample, g
W_w	Weight of water in sample, g
γ	Unit weight, lb/ft^3
γ_d	Dry density of solids, g/ℓ or lb/ft^3
γ_w	Density of water, g/ℓ or lb/ft^3
ΔH	Settlement (change in thickness) of the layer at the completion of primary consolidation, ft
ΔH_{tu}	Settlement of the layer at the time t_u , ft
ΔV	Change in volume of fine-grained channel sediment after disposal in the containment area
Δp	Increase in loading (change in consolidation pressure), lb/ft^2

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Guidelines for designing, operating and managing dredged material containment areas / [by Michael R. Palermo, Raymond L. Montgomery, and Marian E. Poindexter]. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

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